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# Estimating Costs for Water Treatment as a Function of Size and Treatment Efficiency

**Culp/Wesner/Culp, Santa Ana, Calif**

**Prepared for**

**Municipal Environmental Research Lab, Cincinnati, Ohio**

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Municipal Environmental Research
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# Estimating Costs for Water Treatment as a Function of Size and Treatment Plant Efficiency

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This interim report discusses unit processes and combinations of unit processes which are capable of removing contaminants included in the National Interim Primary Drinking Water Standards. Construction and Operation and Maintenance cost curves are presented for 30 unit processes, which are considered to be especially applicable to contaminant removal. The Final Report for this project will include similar cost curves for over 100 unit processes. All costs are presented in terms of January 1978 dollars, but a discussion is included on cost updating. For construction cost, either of two methods may be used. One is to use indices which are specific in the eight categories used to determine construction cost. The second is use of an all-encompassing index, such as ENR Construction Cost Index. Operation and maintenance requirements may be readily updated, or adjusted to local conditions, since labor requirements are expressed in hours per year, and electrical requirements in kilowatt-hours per year.

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# ESTIMATING COSTS FOR WATER TREATMENT AS A FUNCTION OF SIZE AND TREATMENT EFFICIENCY

Robert C. Gumerman
Russell L. Culp
Sigurd P. Hansen

Culp/Wesner/Culp
Consulting Engineers
Santa Ana, California 92707

Contract No. CI-76-0288

Project Officer

Robert M. Clark
Water Supply Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

## FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment and management of wastewater and solid and hazardous water pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The cost of water treatment processes which may be used for the removal of contaminants included in the National Interim Primary Drinking Water Regulations is of interest to the EPA, State and local agencies, and consulting engineers. This Interim Report presents construction and operation and maintenance cost curves for thirty unit processes which are especially applicable, either individually or in combination, for the removal of contaminants contained in the Regulations.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

## ABSTRACT

This Interim Report discusses unit processes and combinations of unit processes which are capable of removing contaminants included in the National Interim Primary Drinking Water Standards. Construction and operation and maintenance cost curves are presented for 30 unit processes which are considered to be especially applicable to contaminant removal. The Final Report for this Project will include similar cost curves for over 100 unit processes.

For each unit process, conceptual designs were formulated, and construction costs were developed for each conceptual design. Construction costs were developed, and are presented in tabular format, in terms of eight individual categories: excavation and sitework; manufactured equipment; concrete; steel; labor; pipe and valves; electrical and instrumentation; and housing. Construction costs are also plotted versus the most appropriate design parameter for the process, such as square feet of surface area for a filter, to allow maximum flexibility in their use.

Operation and maintenance requirements were determined individually for three categories: energy; maintenance material; and labor. Energy requirements were determined separately for building requirements and process requirements.

All costs are presented in terms of January, 1978 dollars, but a discussion is included on cost updating. For construction cost, either of the two methods may be used. One is to use indices which are specific to the eight categories used to determine construction cost. The second is use of an all encompassing index, such as the ENR Construction Cost Index. Operation and maintenance requirements may be readily updated, or adjusted to local conditions, since labor requirements are expressed in hours per year, and electrical requirements in kilowatt-hours per year.

This report was submitted in fulfillment of Contract No. CI-76-0288 by Culp/Wesner/Culp under the sponsorship of the U.S. Environmental Protection Agency. Zurheide-Herrmann, subcontractor, checked the validity of all the construction cost data that were developed.

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# I. SCOPE

This report is an Interim Report for the Project entitled, "Estimating Costs for Water Treatment as a Function of Size and Treatment Efficiency". This Interim Report describes the methods used to develop cost curves, describes methods of updating the cost curves, and presents construction and operation and maintenance curves for 30 unit processes useful for removal of contaminants which are included in the National Interim Primary Drinking Water Regulations. The Final Report will include cost curves for approximately 100 unit processes.

## II. INTRODUCTION

The Safe Drinking Water Act (PL 93-523) enacted on December 16, 1974 empowered the Administrator of the Environmental Protection Agency (EPA) to control the quality of the drinking water in public water systems by regulation and other means. The Act specified a three stage mechanism for the establishment of comprehensive regulations for drinking water quality.

1. Promulgation of National Interim Primary Drinking Water Regulations.
2. A study to be conducted by the National Academy of Sciences (NAS) within two years of enactment on the human health effects of exposure to contaminants in drinking water.
3. Promulgation of Revised National Primary Drinking Water Regulations based upon the NAS report.

National Interim Primary Drinking Water Regulations were promulgated on December 24, 1975 and July 9, 1976, and became effective on June 24, 1977. These Regulations were based on the Public Health Service Drinking Water Standards of 1962, as revised by the EPA Advisory Committee on the Revisions and Application of the Drinking Water Standards, and are intended to protect health to the maximum extent feasible using treatment methods which are generally available and take cost into consideration. The National Interim Primary Drinking Water Regulations contain maximum contaminant levels (MCL) and monitoring requirements for 10 inorganic chemicals, 6 organic pesticides, two categories of radionuclides, coliform organisms and turbidity. An Amendment to the National Interim Primary Drinking Water Regulations was proposed on February 9, 1978. This amendment would establish regulations for total trihalomethanes and establish treatment technique requirements for the control of synthetic organic chemicals for community water systems serving a population of more than 75,000. Secondary Drinking Water Regulations were proposed by EPA on March 31, 1977.

A listing of the contaminants presently included in the National Interim Primary Drinking Water Standards, along with the MCL for each contaminant, is shown in Tables 1 and 2, with the exception of coliform organisms. The MCL for coliform organisms is dependent upon whether the membrane filter technique or the fermentation tube technique is utilized, and the sample size if the latter is utilized. Table 3 presents the MCL for coliform organisms.

The Primary Regulations are devoted to contaminants affecting the health of consumers, while secondary regulations include those contaminants which primarily deal with aesthetic qualities of drinking water. The Interim Primary Regulations are applicable to all public water systems and are

## TABLE 1

## CONTAMINANTS INCLUDED IN THE NATIONAL INTERIM PRIMARY DRINKING WATER REGULATION AND THE MCL'S

| Contaminant | MCL |
|---|---|
| Arsenic | 0.05 mg/1 |
| Barium | 1.0 mg/1 |
| Cadmium | 0.01 mg/1 |
| Chromium | 0.05 mg/1 |
| Lead | 0.05 mg/1 |
| Mercury | 0.002 mg/1 |
| Nitrate (as N) | 10.0 mg/1 |
| Selenium | 0.01 mg/1 |
| Silver | 0.05 mg/1 |
| Endrin | 0.002 mg/1 |
| Lindane | 0.004 mg/1 |
| Toxaphene | 0.005 mg/1 |
| 2, 4-D | 0.1 mg/1 |
| 2, 4, 5 - TP (Silvex) | 0.01 mg/1 |
| Methoxychlor | 0.1 mg/1 |
| Alpha Emitters | |
| Radium - 226 | 5 pCi/1 |
| Radium - 228 | 5 pCi/1 |
| Gross Alpha Activity (Excluding radon and uranium) | 15 pCi/1 |
| Beta and Photon Emitters* | |
| Tritium | 20 pCi/1 |
| Strontium | 8 pCi/1 |
| Turbidity | 1 turbidity unit** |

*Based upon a water intake of 2 liters/day. If gross beta particle activity exceeds 50 pCi/1, other nucleides should be identified and quantified on the basis of 2 liters/day intake.

**One turbidity unit based on a monthly average. Up to 5 turbidity units may be allowed for the monthly average if it can be demonstrated that no interference occurs with disinfection or microbiological determinations.

## TABLE 2

## MAXIMUM CONTAMINANT LEVEL FOR FLUORIDE

| Temperature | | |
|---|---|---|
| °F | °C | MCL, mg/1 |
| 53.7 and below | 12.0 and below | 2.4 |
| 53.8 to 58.3 | 12.1 to 14.6 | 2.2 |
| 58.4 to 63.8 | 14.7 to 17.6 | 2.0 |
| 63.9 to 70.6 | 17.7 to 21.4 | 1.8 |
| 70.7 to 79.2 | 21.5 to 26.2 | 1.6 |
| 79.2 to 90.5 | 26.3 to 32.5 | 1.4 |

## TABLE 3

## MAXIMUM CONTAMINANT LEVELS FOR COLIFORM ORGANISMS

I. When the membrane filter technique is used the number of coliform bacteria shall not exceed any of the following:

   A. One per 100 milliliters as the arithmetic mean of all samples examined per month;
   B. Four per 100 milliliters in more than one sample when less than 20 are examined per month; or
   C. Four per 100 milliliters in more than five percent of the samples when 20 or more are examined per month.

II. When the fermentation tube method and 10 milliliter standard portions are used, coliform bacteria shall not be present in any of the following:

   A. More than 10 percent of the portions in any month;
   B. Three or more portions in more than one sample when less than 20 samples are examined per month; or
   C. Three or more portions in more than five percent of the samples when 20 or more samples are examined per month.

III. When the fermentation tube method and 100 milliliter standard portions are used, coliform bacteria shall not be present in any of the following:

   A. More than 60 percent of the portions in any month;
   B. Five portions in more than one sample when less than five samples are examined per month; or
   C. Five portions in more than 20 percent of the samples when five or more samples are examined per month.

enforceable by EPA or the States which have accepted primacy. Secondary regulations are not Federally enforceable and are intended as guidelines for the States.

The National Academy of Sciences (NAS) Summary Report was delivered to Congress on May 26, 1977, and, the full report, "Drinking Water and Health", was delivered on June 20, 1977. The NAS Summary Report was also published in the Federal Register, Monday, July 11, 1977. Based on the completed National Academy of Sciences Report and the findings of the Administrator, EPA will publish:

1. Recommended MCL's (health goals) for substances in drinking water which may have adverse effects on humans. These recommended levels will be selected so that no known or anticipated adverse effects would occur, allowing an adequate margin of safety. A list of contaminants which may have adverse effects, but which cannot be accurately measured in water, will also be published.
2. Revised National Primary Drinking Water Regulations. These will specify MCL's or require the use of treatment techniques. MCL's will be as close to the recommended levels for each contaminant as is feasible. Required treatment techniques for those substances which cannot be measured, will reduce their concentrations to a level as close to the recommended level as is feasible. Feasibility is defined in the Act as use of the best technology, treatment techniques and other means which the Administrator finds are generally available (taking costs into consideration).

On February 9, 1978, the EPA proposed to amend the National Interim Primary Drinking Water Regulations by adding regulations for organic chemical contaminants in drinking water. The proposed amendment consisted of two parts:

1. A Maximum Contaminant Level (MCL) of 0.10 mg/l (100 parts per billion) for total trihalomethanes (TTHM'S), including chloroform.
2. A treatment technique requiring the use of granular activated carbon for the control of synthetic organic chemicals. Three criteria which the granular activated carbon must achieve are: an effluent limitation of 0.5 μg/l for low molecular weight halogenated organics (excluding trihalomethanes); a limit of 0.5 mg/l for effluent total organic carbon concentration when fresh activated carbon is used; and the removal of at least 50 percent of influent total organic carbon when fresh activated carbon is used.

These proposed amendments are initially applicable to community water systems serving a population of more than 75,000.

## III. PURPOSE AND OBJECTIVES

The principal purpose of this Project is to delineate water treatment processes, or process combinations, which can remove one or more of the contaminants included in the Interim Regulations, and then to develop construction and operation and maintenance cost curves for the required unit processes. To facilitate the usefulness of the curves, separate curves are being developed for flows ranging between 2,500 gpd and 1 mgd, and between 1 mgd and 200 mgd. This separation was made because many processes applicable to one range are not applicable to the other range, and often when a process is applicable to both ranges, the conceptual design of the components varies significantly. Additionally, the economy of scale inherent to treatment of larger flows often causes a dramatic change in the slope of cost curves, commonly in the 1 to 5 mgd range.

Other objectives of the Project include a literature search on the effectiveness of virus and asbestos removal by various unit processes, and the development of cost curves for the identified processes. The Project will also develop a computer program which can be used to update costs and to determine the cost of various combinations of unit process.

This Interim Report is being published to present a portion of the information which has been developed to the present time. Cost curves for 30 unit processes are included in this Interim Report, while the Final Report will include cost curves for approximately 100 unit processes. The decision to produce an Interim Report was made by the EPA Water Supply Research Division, MERL, following numerous requests from the EPA Regional Offices, State agencies, and consulting engineers for advance information. The information presented in this Interim Report is intended to be useful to the EPA, State and local agencies, consulting engineers, and local elected officials. The cost curves were developed to a high level of accuracy, and are intended to allow cost comparisons between alternative processes and combinations of processes. They will also be useful for long range budget planning by utility managers.

This Interim Report includes a detailed discussion on a contaminant by contaminant basis, of treatment processes which can be used for the removal of each. Following this discussion are the cost curves for 30 unit processes, along with a description of the basic conceptual designs used to develop the curves.

The processes were selected for inclusion in the Interim Report based upon applicability to one or more of the following criteria:

1. Processes especially suitable for small water systems.
2. Processes which provide soluble organic removal.
3. Processes which provide disinfection.
4. Processes required for direct filtration.
5. Reverse osmosis and ion exchange processes.
6. Other curves completed to date.

The unit processes which are included in this Interim Report are:

1. Package Pressure Filtration Plants
2. Package Gravity Filtration Plants
3. Package Complete Treatment Plants
4. Conversion of Sand Filter to Carbon Contactor
5. Pressure Carbon Contactors
6. Gravity Carbon Contactors - Concrete Construction
7. Gravity Carbon Contactors - Steel Construction
8. Off-Site Regional Carbon Regeneration
9. Multiple Hearth Granular Carbon Regeneration
10. Granular Activated Carbon - Material Cost
11. Chlorine Feed Systems
12. Ozone Generating Systems
13. On-Site Chlorine Generation Systems
14. Chlorine Dioxide Feed Systems
15. Ammonia Feed Facilities
16. Alum Feed Systems
17. Polymer Feed Systems
18. Rapid Mix
19. Flocculation
20. Gravity Filtration Structure
21. Filter Media
22. Hydraulic Surface Wash
23. Backwash Pumping
24. Reverse Osmosis
25. Ion Exchange - Softening
26. Ion Exchange - Nitrate Removal
27. Activated Alumina - Fluoride Removal
28. Powdered Activated Carbon Feed Systems
29. Pressure Filtration - flows greater than 1 mgd
30. Continuous Automatic Backwash Filter

## IV. TREATMENT TECHNIQUES FOR CONTAMINANT REMOVAL

### Basic Water Treatment Techniques

A variety of conventional water treatment techniques may be utilized for the removal of contaminants considered within this Report. The techniques which are applicable for each of the various contaminants are listed in Table 4, on a contaminant by contaminant basis. A detailed listing of unit processes comprising each of these techniques is shown in Table 5. Also shown in Table 5 are the MCL values for each contaminant as well as the highest initial concentration (Ci) of the contaminant which can be reduced to the MCL by a single pass through the particular treatment technique. If a single pass will not reduce the contaminant concentration to less than the MCL, then multiple steps of the same process or two or more different processes in series may be utilized. The techniques were selected based upon their ability to reduce the initial contaminant concentration from a maximum of 10 times the MCL, to less than the MCL.

As may be observed in Tables 4 and 5, the majority of the slightly soluble inorganic constituents may be removed by conventional coagulation, while highly soluble inorganics are generally removed by reverse osmosis or ion exchange, and soluble organics are generally removed by adsorptive interaction with activated carbon. Although these are generalizations, it is important to recognize that there is a great degree of commonality between many contaminants, and that most treatment techniques are applicable to the removal of more than one contaminant. Following is a detailed discussion on a contaminant by contaminant basis, of treatment techniques and process combinations which are listed in Tables 4 and 5.

### ARSENIC - MCL = 0.05 mg/l

Arsenic in water may be in either the trivalent (+3) form known as arsenite ($AsO_2^-$) or the pentavalent (+5) form known as arsenate ($AsO_4^{-3}$). Conversion of the trivalent form to the pentavalent form may be by biological or chemical oxidation. Reduction of the oxidized form generally occurs by anaerobic biological action. The trivalent form is more toxic than the pentavalent form. Elemental arsenic is essentially insoluble in water, and organic arsenic forms are rarely found. Arsenic contributions from natural sources, generally only in certain portions of the western United States, are due to leaching of native arsenic from rock formations and leaching of mine tailings from copper, gold, and lead refining operations. Industrial related contributors are from the afore mentioned refining operations, pesticides, herbicides, and insecticides, and fossil fuel combustion.

## TABLE 4

## MOST EFFECTIVE TREATMENT METHODS FOR CONTAMINANT REMOVAL

| Contaminant | Most Effective Treatment Methods |
|---|---|
| Arsenic: | $As^{+5}$ - Ferric sulfate coagulation, pH 6-8; Alum coagulation, pH 6-7; Excess lime softening.<br>$As^{+3}$ - Ferric sulfate coagulation, pH 6-8; Alum coagulation, pH 6-7; Excess lime softening.<br>NOTE: Oxidation required before treatment for $As^{+3}$ |
| Barium: | Lime softening, pH 10-11; Ion exchange softening. |
| Cadmium: | Ferric sulfate coagulation, above pH 8; Lime softening; Excess lime softening. |
| Chromium: | $Cr^{+3}$ - Ferric sulfate coagulation, pH 6-9; Alum coagulation, pH 7-9; Excess lime softening.<br>$Cr^{+6}$ - Ferrous sulfate coagulation, pH 7-9.5. |
| Coliform Organisms: | Disinfection; Coagulation plus disinfection. |
| Fluoride: | Ion exchange with activated alumina; Lime softening. |
| Lead: | Ferric sulfate coagulation, pH 6-9; Alum coagulation, pH 6-9; Lime softening; Excess lime softening. |
| Manganese: | Inorganic - Sedimentation/Filtration.<br>Organic - Alum coagulation, pH 9-9.6. |
| Mercury: | Inorganic - Ferric sulfate coagulation, pH 7-8.<br>Organic - Granular Activated Carbon. |
| Nitrate: | Ion exchange. |
| Organic Contaminants: | Powdered activated carbon; granular activated carbon. |
| Radium: | Lime softening. |
| Selenium: | $Se^{+4}$ - Ferric sulfate coagulation, pH 6-7; Ion exchange; Reverse osmosis.<br>$Se^{+6}$ - Ion exchange; Reverse osmosis. |
| Silver: | Ferric sulfate coagulation, pH 7-9; Alum coagulation, pH 6-8; Lime softening; Excess lime softening. |
| Sodium: | Ion exchange; Reverse osmosis. |
| Sulfate: | Ion exchange; Reverse osmosis. |
| Turbidity: | Alum coagulation, filtration. |

TABLE 5

## MATRIX OF WATER TREATMENT PROCESSES USEFUL IN MEETING THE NATIONAL INTERIM PRIMARY DRINKING WATER REGULATION MAXIMUM CONTAMINANT LEVELS, WITH MAXIMUM RAW WATER CONCENTRATIONS (Ci) SHOWN

| Item No. | Substance To Be Removed | MCL mg/l | Pre-Disinfection | Pre-Sedimentation | Alum | Coagulation |  | Lime Softening | pH Adjustment |  | Mixing | Flocculation | Sedimentation | Filtration | Post Disinfection | Oxidation |  |  | Reverse Osmosis | Ion Exchange | Activated Carbon |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Ferric Sulfate | Ferrous Sulfate |  | Lower | Raise |  |  |  |  |  | $Cl_2$ | Ozone | KMnO4 |  |  | Powdered | Granular |
| IA | Low Coliform Waters | 1/100ml |  |  |  |  |  |  |  |  |  |  |  |  | Ci=1–100 MPN/100ml |  |  |  |  |  |  |  |
| IB | Mod. Coliform Waters | 1/100ml | X |  | X |  |  |  |  |  |  |  |  | X | Ci=<5,000 MPN/100ml |  |  |  |  |  |  |  |
| IC | High Coliform Waters | 1/100ml | X |  | X |  |  |  |  |  | X | X | X | X | Ci=<20,000 MPN/100ml |  |  |  |  |  |  |  |
| ID | Excessively High Coliform Waters | 1/100ml |  | Special treatment methods as approved by State |  |  |  |  |  |  |  |  |  |  | Ci=>20,000 MPN/100ml |  |  |  |  |  |  |  |
| IIA | Low Turbidity Waters (Ci = 1 to 25 Tu) | 1 |  |  | X |  |  |  |  |  |  |  |  | X | X |  |  |  |  |  |  |  |
| IIB | Mod. Turbidity Waters (Ci = 25 to 1,000 Tu) | 1 |  |  | X |  |  |  |  |  | X | X | X | X | X |  |  |  |  |  |  |  |
| IIC | High Turbidity Waters (Ci = 1,000 Tu) | 1 |  | X | X |  |  |  |  |  | X | X | X | X | X |  |  |  |  |  |  |  |
| IIIA1 | Arsenic, pentavalent (Ci = 1.0 mg/l) | 0.05 |  |  | X or | X |  |  | <7.5 |  | X | X | X | X | X |  |  |  |  |  |  |  |
| IIIA2 | As 5 (Ci = 1.0 mg/l) | 0.05 |  | Removed coincidentally in processes shown under Items IC, IIB, or IIC at pH < 7.5 and with alum or ferric sulfate dosage =20–30 mg/l |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| IIIA3 | Arsenic, pentavalent | 0.05 |  |  |  |  |  | Ci=1.0 mg/l | X | >10.8 | X | X | X | X | X |  |  |  |  |  |  |  |
| IIIB | Arsenic, trivalent (Ci = 1.0 mg/l) | 0.05 |  |  |  |  |  |  |  |  |  |  |  |  |  | X or | X or | X – followed by treatment shown under Items IIIA1, IIIA2, or IIIA3 above |  |  |  |  |
| IIIC | Arsenic, trivalent | 0.05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Act. Alumina or bone char |  |  |
| IIID | Arsenic, trivalent | 0.05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Ci=0.33 mg/l |  |  |  |
| IVA | Barium | 1 |  |  |  |  |  | Ci=10.0 mg/l | X | 10–11 | X | X | X | X | X |  |  |  |  |  |  |  |
| IVB | Barium | 1 |  | (Ci limited by raw—finished water blending, so as not to exceed barium MCL) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Softening Resins |  |  |
| IVC | Barium | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Ci=45 mg/l |  |  |  |
| VA | Cadmium | 0.010 |  |  |  |  |  | Ci=0.5 mg/l | X | 8.5–11 | X | X | X | X | X |  |  |  |  |  |  |  |
| VB | Cadmium (Ci=0.1 mg/l) | 0.010 |  |  |  | X |  |  |  | 8.0 | X | X | X | X | X |  |  |  |  |  |  |  |
| VB | Cadmium (Ci=0.1 mg/l) | 0.010 |  |  | X |  |  |  |  | 9.0 | X | X | X | X | X |  |  |  |  |  |  |  |
| VC | Cadmium (Ci=0.1 mg/l) | 0.010 |  | Removed coincidentally in processes shown under Items IC, IIB, or IIC at pH = 8 for ferric sulfate and 9.0 for alum |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| VIA1 | Cr+3 (Ci = 0.5 mg/l) | 0.05 |  |  |  | pH 6.5–9.3 |  |  |  |  | X | X | X | X | X |  |  |  |  |  |  |  |
| VIA1 | Cr+3 (Ci = 0.5 mg/l) | 0.05 |  |  | pH 6.7–8.5 |  |  |  |  |  | X | X | X | X | X |  |  |  |  |  |  |  |
| VIA2 | Cr+3 (Ci = 0.5 mg/l) | 0.05 |  | Removed coincidentally in processes shown under Items IC, IIB, or IIC at pH 6.7 to 8.5 for alum and pH 6.5 to 9.3 for ferric sulfate |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| VIA3 | Chromium, trivalent | 0.05 |  |  |  |  |  | Ci=2.5 mg/l | X | >10.6 | X | X | X | X | X |  |  |  |  |  |  |  |
| VIB | Chromium, hexavalent | 0.05 |  |  |  |  | Ci=5 mg/l |  | (X or | X) | X | X | X | X | X |  |  |  |  |  |  |  |
| VIC | Chromium, hexavalent | 0.05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Ci=0.4 mg/l |  |  |  |
| VIIA | Lead | 0.05 |  |  |  |  |  | Ci=1.7 mg/l | X | 8.5–11.3 | X | X | X | X | X |  |  |  |  |  |  |  |

TABLE 5 (CONT'D)

## MATRIX OF WATER TREATMENT PROCESSES USEFUL IN MEETING THE NATIONAL INTERIM PRIMARY DRINKING WATER REGULATION MAXIMUM CONTAMINANT LEVELS, WITH MAXIMUM RAW WATER CONCENTRATIONS (Ci) SHOWN

| Item No. | Substance To Be Removed | MCL mg/l | Pre-Disinfection | Pre-Sedimentation | Coagulation | | | | pH Adjustment | | Mixing | Flocculation | Sedimentation | Filtration | Post Disinfection | Oxidation | | | Reverse Osmosis | Ion Exchange | Activated Carbon | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Alum | Ferric Sulfate | Ferrous Sulfate | Lime Softening | Lower | Raise | | | | | | $Cl_2$ | Ozone | KMnO4 | | | Powdered | Granular |
| VIIA | Lead | 0.05 | | Removed coincidentally in process shown under Items IC, IIB, or IIC | | | | | | | | | | | | | | | | | | |
| VIIB | Lead | 0.05 | | | | | | | | | | | | | | | | | | | | |
| VIIIA1 | Inorganic Mercury (Ci = 0.1 mg/l) | 0.002 | | | | | | | | | | | | | | | | | Ci = 0.4 mg/l | Cation-Anion | | |
| VIIIA2 | Inorganic Mercury | 0.002 | | | | Ci 0.07 mg/l | | | | | X | X | X | X | X | | | | | | X | |
| VIIIA2 | Inorganic Mercury | 0.002 | | | Ci 0.006 mg/l | | | | | | X | X | X | X | X | | | | | | X | |
| VIIIA3 | Inorganic Mercury | 0.002 | | | | | | Ci = 0.007 mg/l | X | 10.7 | X | X | X | X | X | | | | | | | |
| VIIIA4 | Inorganic Mercury | 0.002 | | | | | | | | | | | | | | | | | | Cation-Anion | | |
| VIIIB1 | Organic Mercury (Ci=0.1 mg/l) | 0.002 | | | | | | | | | | | | | | | | | | | | Ci=0.01 mg/l |
| VIIIB2 | Organic Mercury | 0.002 | | | X | | | | | | X | X | X | X | X | | | | | | X | |
| VIIIB3 | Organic Mercury | 0.002 | | | | | | | | | | | | | | | | | | | | Ci 0.01 mg/l |
| IXA | Nitrate | 10 | | | | | | | | | | | | | | | | | Ci = 115 mg/l | NO3 Selective (Ci=225 mg/l) | | |
| XA1 | Selenium, quadrovalent | 0.01 | | | | Ci=0.05 mg/l | | | | | X | X | X | X | X | | | | | | | |
| XA2 | Se+4 | 0.01 | | | | | | | | | | | | | | | | | | Ci=0.33 mg/l | | |
| XA2 | Se+4 | 0.01 | | | | | | | | | | | | | | | | | Ci=0.33 mg/l | | | |
| XB | Selenium, hexavalent | 0.01 | | | | | | | | | | | | | | | | | | Ci=0.33 mg/l | | |
| XB | Se+6 | 0.01 | | | | | | | | | | | | | | | | | Ci=0.33 mg/l | | | |
| XIA | Silver (Ci=0.17 mg/l) | 0.05 | | | ( X or | X) | | | | | X | X | X | X | X | | | | | | | |
| XIB | Silver (Ci=0.17 mg/l) | 0.05 | | Removed coincidentally in process shown under Items IC, IIB, or IIC if ferric sulfate or alum dosage is adequate | | | | | | | | | | | | | | | | | | |
| XIC | Silver (Ci=0.17 mg/l) | 0.05 | | | | | | | X | 9.0 | X | X | X | X | X | | | | | | | |
| XIC | Silver (Ci=0.50 mg/l) | 0.05 | | | | | | | X | 11.5 | X | X | X | X | X | | | | | | | |
| XID | Silver | 0.05 | | | | | | | | | | | | | | | | | Ci=0.83 mg/l | | | |
| XIIA | Fluoride | Varies w air Temp. | | | | | | | | | | | | | | | | | | Act. Alumina or Bone char | | |
| XIIB | Fluoride (hard waters) | 1.4 to | | | | | | X | X | 10.6 | X | X | X | X | X | | | | | | | |
| XIIC | Fluoride (soft waters) | 2.4 | | | 200–500 mg/l | | | | | | X | X | X | X | X | | | | | | | |
| XIII | Organic chemicals | – | | | | | | | | | | | | | | | | | | | ( X or | X ) |
| XIVA | Asbestos | – | | With the employment of proper operating strategies, asbestos will be removed by the processes shown under Items IB, IC, IIA, IIB, or IIC | | | | | | | | | | | | | | | | | | |
| XIVB | Asbestos | – | | | | | | | | | | | | | | | | | | | | |
| XV | Virus | – | | With the employment of proper operating strategies, virus will be removed by the processes shown under Items IA, IB, IC, ID, IIA, IIB, or IIC | | | | | | | | | | | | | | | | | | |

TABLE 5 (CONT'D)

## MATRIX OF WATER TREATMENT PROCESSES USEFUL IN MEETING THE NATIONAL INTERIM PRIMARY DRINKING WATER REGULATION MAXIMUM CONTAMINANT LEVELS, WITH MAXIMUM RAW WATER CONCENTRATIONS (Ci) SHOWN

| Item No. | Substance To Be Removed | MCL mg/l | Pre-Disinfection | Pre-Sedimentation | Coagulation | | | | pH Adjustment | | Mixing | Flocculation | Sedimentation | Filtration | Post Disinfection | Oxidation | | | Reverse Osmosis | Ion Exchange | Activated Carbon | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Alum | Ferric Sulfate | Ferrous Sulfate | Lime Softening | Lower | Raise | | | | | | $Cl_2$ | Ozone | $KMnO_4$ | | | Powdered | Granular |
| XVIA | Radium (low hardness waters) | 5.0 pCi/l | | | | | | Ci = 30 pCi/l | | | | | | | | | | | | | | |
| | Radium (medium hardness waters) | 5.0 pCi/l | | | | | | Ci = 70 pCi/l | | | | | | | | | | | | | | |
| | Radium (high hardness waters) | 5.0 pCi/l | | | | | | Ci = 165 pCi/l | | | | | | | | | | | | | | |
| XVIB | Radium | 5.0 pCi/l | | | | | | | | | | | | | | | | | | | | |
| XVIC | Radium | 5.0 pCi/l | | | | | | | | | | | | | | | | | 100 pCi/l | 100 pCi/l | | |
| XVIIA | Sodium | 20 | | | | | | | | | | | | | | | | | | Ci = 133 mg/l | | |
| XVIIB | Sodium | 20 | | | | | | | | | | | | | | | | | | | | |
| XVIIIA | Sulfate | 250 | | | | | | | | | | | | | | | | | Ci = 285 mg/l | | | |
| XVIIIB | Sulfate | 250 | | | | | | | | | | | | | | | | | Ci = 3570 mg/l | Ci = 8300 mg/l | | |
| XIXA | Mn. inorganic unoxidized | 0.05 | | | | | | | | | | | | | | | | | | | | |
| XIXB | Manganese, inorganic | 0.05 | | | | | | | | | | | X | X | | X | | X | | X | | |
| XIXC | Manganese, organic | 0.05 | | | X or X | | | X | | 9.0–9.6 | X | X | X | X | X | X | | X | | | | |

Pentavalent (+5) Arsenic - Initial concentration to 1.0 mg/l

Pentavalent arsenic can be treated by pH adjustment (if required) to pH 6 - 7 or pH 6 - 8 for alum or ferric sulfate addition, respectively. To meet the MCL of 0.05 mg/l, coagulant dosages up to 20 - 30 mg/l may be required, followed by rapid mixing, 30 minutes of flocculation, settling at a basin overflow rate of 24,450 Lpd/sq.M (600 gpd/sf) and filtration at 81.4 to 203.4 Lpd/sq.M (2 to 5 gpm/sf).

Pentavalent arsenic may also be removed coincidently during the treatment of moderate to high coliform concentrations, or high turbidity, by chemical clarification, provided that proper attention is given to pH and alum or ferric sulfate dosage (20 to 30 mg/l).

Pentavalent arsenic can also be removed by lime softening at pH above 10.8. Treatment would consist of lime addition and mixing, 30 minutes of flocculation, settling at a basin overflow rate of 24,450 Lpd/sq.M (600 gpd/sf) with 2 hours detention, pH adjustment, and filtration at 81.4 to 203.4 Lpd/sq.M (2 to 5 gpm/sf).

Trivalent (+3) Arsenic - Initial concentration to 1.0 mg/l

Trivalent arsenic can be oxidized to the pentavalent form by the use of chlorine, ozone, or potassium permanganate and then removed by the treatment processes previously described for the pentavalent form.

Pentavalent (+5) and Trivalent Arsenic

Both valences of arsenic may be removed by ion exchange using activated alumina or commercial anion resins. Insufficient data is available at the present time to determine the maximum concentration which can be reduced to the 0.05 mg/l MCL. Arsenic may also be reduced by about 85 percent using reverse osmosis, making such treatment applicable to raw waters containing up to 0.33 mg/l of arsenic.

## BARIUM - MCL = 1.0 mg/l

Barium is only present in trace amounts in most surface water and ground water supplies. The most common occuring natural form of barium is barite (barium sulfate) which has a low solubility, especially in waters containing sulfate. Soluble forms of barium are very toxic, whereas insoluble forms are considered non-toxic. Barite is used principally as a drilling mud in oil and gas well drilling, while other barium compounds are used in the production of glass, paint, rubber, ceramics, and the chemical industry.

Lime softening in the pH range 10 to 11 may be used to treat waters containing 1.0 to 10.9 mg/l of barium. Treatment consists of lime addition and mixing, 30 minutes of flocculation, settling at a basin overflow rate of 24,450 Lpd/sq.M (600 gpd/sf) with 2 hours detention, pH adjustment, and filtration at 81.4 to 203.4 Lpd/sq.M (2 to 5 gpm/sf).

Ion exchange systems similar to those used for softening (calcium and magnesium removal) may be used for barium concentrations exceeding the 1.0 mg/l MCL. The maximum concentration of barium in the raw water is limited if the usual method of blending raw and treated water is to be practiced for hardness concentration control and stabilization of the treated water. The amount of raw water used for blending must necessarily be controlled to insure that the 1.0 mg/l MCL for barium is not exceeded in the blended mixture.

Barium concentrations up to 45 mg/l may be reduced below the 1.0 mg/l MCL using reverse osmosis operating at about 98 percent removal. Depending upon water composition, however, there may be difficulties with membrane fouling in treatment of high barium waters.

## CADMIUM - MCL = 0.01 mg/l

Cadmium generally does not present a water quality problem from naturally occurring sources, although it may occur in leachates from iron and other ore mining and smelting operations. Carbonate and hydroxide forms found at higher pH are relatively insoluble, while other forms are soluble. Water supply contamination from industries may occur from electroplating industry wastes, sludges resulting from paint manufacture, battery manufacturing, metallurgical alloying, ceramic manufacturing, and textile printing.

Lime softening in the pH range of 8.5 to 11.3 may be used to treat waters containing 0.010 to 0.50 mg/l of cadmium. The amount of lime which must be added increases with increasing concentrations of cadmium in the raw water. Treatment would consist of lime addition and mixing, 30 minutes of flocculation, settling at a basin overflow rate of 24,450 Lpd/sq.M (600 gpd/sf) with 2 hours detention, pH adjustment, and filtration at 81.4 to 203.4 Lpd/sq.M (2 to 5 gpm/sf).

Raw water containing 0.010 to 0.10 mg/l of cadmium can be treated by pH adjustment to 8.0 for ferric sulfate coagulation and 9.0 for alum coagulation at dosages of 30 mg/l, followed by mixing, 30 minutes of flocculation, settling at a basin overflow rate of 24,450 Lpd/sq.M (600 gpd/sf), and filtration at 81.4 to 203.4 Lpd/sq.M (2 to 5 gpm/sf).

Cadmium at initial concentrations of 0.010 to 0.10 mg/l is removed coincidentally in the treatment of high coliform waters and moderate or high turbidity waters, provided proper pH conditions are maintained (8.0 for ferric sulfate and 9.0 for alum), and sufficient coagulant is used.

## CHROMIUM - MCL = 0.05 mg/l

Chromium in water supplies may be present in either the trivalent (+3) form or the hexavalent (+6) form. Unless pH is very low, the hexavalent form predominates. The hexavalent form is the more toxic form, and is also the more difficult form to remove. Most forms of hexavalent chromium treatment incorporate reduction of hexavalent chromium to trivalent chromium prior to removal.

Chromium occurs naturally as chromite ($CrO_3$) or chrome iron ore ($FeO \cdot Cr_2O_3$). The major source of chromium in water supplies is not from natural sources, but rather from industrial operations. Operations involving metal plating, alloy preparation, tanning, wood preservation, corrosion inhibition, and pigments for inks, dyes and paints are all potential sources.

### Trivalent (+3) Chromium

Trivalent chromium can be reduced to the MCL of 0.05 mg/l by coagulation: (a) with 30 mg/l ferric sulfate in the pH range of 6.5 to 9.3 and raw water concentrations up to 2.5 mg/l, or (b) with 30 mg/l of alum in the pH range of 6.7 to 8.5 and raw water concentrations up to 0.5 mg/l. The chemical treatment should be followed by mixing, 30 minutes flocculation, settling at basin overflow rates of 24,450 Lpd/sq.M (600 gpd/sf), and filtration at 81.4 to 203.4 Lpd/sq.M (2 to 5 gpm/sf). This type of treatment is similar to the treatment required for high coliform and moderate or high turbidity, and trivalent chromium is removed along with these contaminants, provided proper attention is given to pH and coagulant dose.

Waters containing up to 2.5 mg/l of trivalent chromium can be treated by lime softening at pH >10.6. Treatment would include lime addition and mixing, 30 minutes of flocculation, settling at a basin overflow rate of 24,450 Lpd/sq.M with 2 hours detention, pH adjustment, and filtration at 81.4 to 203.4 Lpd/sq.M (2 to 5 gpm/sf).

Pre-oxidation of raw water containing trivalent chromium is normally not practiced, since the trivalent form would be converted to hexavalent chromium, making removal more difficult.

### Hexavalent (+6) Chromium

Raw water concentrations up to 5.0 mg/l of hexavalent chromium can be treated using a special ferrous sulfate coagulation process in which pH adjustment to the 6.5 to 9.3 range is made several minutes after coagulation. Chemical treatment should be followed by mixing, 30 minutes flocculation, settling at basin overflow rates of 24,450 Lpd/sq.M (600 gpd/sf), and filtration at 81.4 to 203.4 Lpd/sq.M (2 to 5 gpm/sf). Pre-chlorination will interfere with this process, as the ferrous ion is oxidized by chlorine and is then unavailable for reduction of hexavalent chromium. Pre-chlorination would necessitate a higher ferrous sulfate dose.

### Trivalent (+3) and Hexavalent (+6) Chromium

Chromium concentrations, trivalent or hexavalent, up to 0.4 mg/l can be reduced to the 0.05 mg/l MCL by reverse osmosis.

## COLIFORM BACTERIA

Coliform bacteria are not pathogens, but are indicators of the presence of contamination from the intestinal tract of humans and warm blooded animals. The advantage of measuring for coliform organisms is the testing procedures are much simpler and more sensitive than for pathogenic bacteria and virus.

The disadvantage of coliform organisms as an indicator is that they may survive longer than some pathogenic organisms and shorter than others.

Low Coliform Waters

Underground waters (only) containing more than one but less than 100 coliform bacteria (M.P.N.) per 100 ml as measured by the monthly arithmetic mean, and having a standard plate count limit of 500 organisms per ml, a fecal coliform density of less than 20 per 100 ml as measured by a monthly arithmetic mean, can be treated using only continuous disinfection. Thirty minutes contact should be utilized prior to discharge of the water into the distribution system.

Moderate Coliform Waters

Water containing not more than 5,000 coliform bacteria (M.P.N.) per 100 ml, should be treated by pre-disinfection with 30 minutes contact, coagulation (with or without settling), filtration at 41.4 to 203.5 Lpm/sq.M (2 to 5 gpm/sf), and continuous post-disinfection with 30 minutes or more contact prior to use.

Excessively High Coliform Waters

Water containing more than 20,000 coliform bacteria per 100 ml or having a fecal coliform count exceeding 2,000 per 100 ml monthly geometric mean are considered undesirable as a source of supply. In the absence of an adequate supply of better bacteriological quality, special methods of treatment may be considered. Proposed special methods of treatment for highly polluted waters should be approved by the State prior to the preparation of plans.

FLUORIDE - MCL = 1.4 to 2.4, depending upon average annual air temperature

Fluoride can be contributed to water from fluoride bearing minerals, although the majority of naturally occuring fluoride compounds are only moderately soluble. Generally, natural sources do not cause excessively high concentrations, although well water supplies in several states do have naturally high concentrations. There are also soluble fluorides from industrial wastewaters in some supply sources. Industries which may discharge significant amounts of fluoride include glass production, fertilizer manufacturing, and aluminum processing.

Water containing excessive fluoride ion may be treated by ion exchange methods using either activated alumina or bone char. Removals by both are pH dependent, with the best removals occuring between pH 5.5 and 7.0. Exchange capacity varies widely among water supplies, and laboratory testing should be utilized to develop design criteria.

Fluoride may also be removed from hard waters by lime softening, followed by filtration. The amount of the fluoride reduction accomplished by lime softening is dependent upon both the initial fluoride concentration and the amount of magnesium removed in the softening process. The fluoride reduction is generally proportional to the square root of the magnesium removed.

For very soft waters (only), flocculation with massive alum dosages of 200 to 500 mg/l is an effective means of fluoride reduction when followed by clarification and filtration as described for moderate turbidity waters.

LEAD - MCL = 0.05 mg/l

Lead in water supplies may result from naturally occuring lead sulfide and lead oxide mineral compounds. The lead solubility may approach 0.4 to 0.8 mg/l, although the solubility limit is lower for alkaline and mineralized sources. Major industrial sources of lead include storage battery manufacture, and gasoline additives, although photographic materials, explosives and lead mining and smelting may also contribute significant amounts.

Naturally occurring carbonates and hydroxides of lead are very insoluble, and treatment of a somewhat turbid surface water by plain sedimentation will reduce 0.5 mg/l of lead to below the 0.05 mg/l MCL.

Coincidental reduction of 2.5 mg to the MCL will also occur during lime soda softening in the pH range of 8.5 to 11.3. Also, initial concentrations up to 1.7 mg/l are reduced to the MCL coincidently, during the treatment of high coliform waters and moderate or high turbidity waters with alum and ferric sulfate.

Reverse osmosis may be used to remove soluble lead concentrations up to 0.4 mg/l. Precautions are necessary, however, to prevent membrane fouling by insoluble lead carbonates and lead hydroxides.

MANGANESE - Secondary Drinking Water Regulation MCL = 0.05 mg/l

Manganese solution from mineral forms is primarily the result of bacterial action or complexation by organic material. Reduced forms of manganese (+2) in water are soluble, while oxidized forms (+4) are insoluble. Acid mine drainage is a principal natural source of manganese in water supplies. Industrial contributions of manganese generally are not significant.

Manganese is included in the Secondary Drinking Water Regulations, and not the Interim Primary Drinking Water Regulations. There is no presently known health danger from manganese, in the oxidized, unoxidized, or organic states, in water supplies. The principal problems with manganese are brown-black stains which it may impart on laundered goods, and taste which it may impart to drinking water.

Unoxidized and Oxidized Inorganic Manganese

Manganese in the absence of iron and organic matter can be oxidized at low pH (7.2 to 8.0) values with chlorine, potassium, permanganate, or previously precipitated manganese. An alternative approach would be aeration at pH 9.4 to 9.6, to oxidize all manganese. The insoluble oxidized form may then be removed by settling and filtration.

### Organic Manganese

Manganese present in water as a complex of organic matter or iron must be treated with lime to pH values of 9.0 to 9.6 before oxidation of manganese will occur. Ferric sulfate coagulation is also especially suitable for waters containing organic manganese.

With these modifications and with oxidation by chlorine or potassium permanganate, manganese, complexed with organic matter or iron can be removed by the conventional treatment processes of mixing, flocculation, settling and filtration.

## MERCURY - MCL = 0.002 mg/l

Organic forms of mercury are significantly more toxic than inorganic forms, and can result from utilization of inorganic forms by bacteria and higher level organisms. Elemental mercury is soluble in aerobic situations, and may form mercuric oxide salts. Generally, such mercuric oxide salts adsorb on sediment and are naturally removed by sedimentation. Mercury in water supplies from natural sources is rare. Industrial sources of mercury include electrical and electronics industries, pulp and paper production, pharmaceuticals, paint manufacture, and agricultural herbicides and fungicides.

### Inorganic Mercury

Chemical coagulation, at pH = 8 with ferric sulfate will treat raw waters containing up to 0.07 mg/l inorganic mercury, and at pH = 7 alum will treat raw waters containing up to 0.006 mg/l inorganic mercury, when followed by the clarification treatment described for moderate turbidity waters. Powdered activated carbon may be used in conjunction with coagulation to increase removals above those obtained by coagulation alone, although dosages significantly above those used for taste and odor control are necessary to provide increased removal.

Lime softening in the pH range of 10.7 to 11.4, followed by filtration can reduce concentrations up to 0.007 mg/l to the MCL.

Cation and anion exchange resins operated in series can reduce inorganic mercury from concentrations up to 0.1 mg/l, to the MCL of 0.002 mg/l. Experiments on such removal are only preliminary, and the removal mechanism is uncertain.

Granular activated carbon at a contact time of only 3.5 minutes can remove 80 percent of the applied inorganic mercury, making this process applicable for treatment of raw water concentrations up to 0.01 mg/l.

### Organic Mercury

Powdered activated carbon can be used in the clarification process described for moderate turbidity waters to remove organic mercury. About 1 milligram per liter of powdered activated carbon is needed for each 0.1 microgram per liter or organic mercury to be removed down to the MCL of 0.002 mg/l.

Similarly to inorganic mercury, granular activated carbon at a contact time of only 3.5 minutes can be used to remove 80 percent of the organic mercury applied, making the process applicable for raw water concentrations up to 0.01 mg/l.

Cation and anion exchange resins operated in series can reduce organic mercury from concentrations up to 0.1 mg/l to the 0.002 mg/l MCL.

## NITRATE - MCL = 45 mg/l as $NO_3^-$

Naturally occurring high nitrate concentrations are very rare. High nitrate concentrations in ground water or surface water are generally the result of direct or indirect contamination by wastewater, animal excrement, or by agricultural fertilization. Industrial discharges from fertilizer manufacturing also represent a potential source of contamination. Nitrate is a relatively stable form of nitrogen, but nitrate may be produced by the biological oxidation of ammonia.

Anion ion exchange resins can be used to reduce nitrates from as high as 221 mg/l to as low as 2.2 mg/l (as $NO_3^-$). Since the MCL is 45 mg/l (as $NO_3^-$), the use of blending can result in a considerable savings in capacity and operational cost.

Reverse osmosis can achieve up to 85 percent removal of nitrate. Thus, concentrations as high as 300 mg/l (as $NO_3^-$) could be reduced to the MCL, or concentrations less than 300 mg/l could be treated to below the MCL and utilized for blending purposes.

## ORGANIC CONTAMINANTS

The six organic pesticides presently included in the Interim Primary Drinking Water Standards are not naturally occurring. Four of these organics (endrin, lindane, toxaphene, methoxychlor) are chlorinated hydrocarbon insecticides. These synthetic organic insecticides may be contributed to water supplies by industrial discharge during manufacture or runoff following use. The remaining two organics (2,4-D and 2,4,5-TP (Silvex)) are chlorophenoxy herbicides, which are generally used for the control of aquatic vegetation. Contamination of water supplies may occur by manufacturing operation and/or use.

Proposed as an amendment to the Primary Standards are total trihalomethanes (TTHM's). Trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and tribromomethane) are not naturally occurring, but are reaction by-products resulting from chlorination of water containing naturally occurring humic and fulvic compounds. Bromide and iodide ions may also be reactants in the process. The criteria for volatile halogenated compounds in the proposed amendment was established as a measure of analysis for a broad range of organic chemicals which are difficult to measure individually and/or are unknown.

For the six organic pesticides of concern, information on removal is only available for four: endrin - MCL = 0.0002 mg/l; lindane - MCL = 0.004 mg/l; toxaphene - MCL = 0.005 mg/l; and 2,4-D - MCL = 0.1 mg/l. No information is available for methoxychlor - MCL = 0.1 mg/l; or 2,4,5-TP (Silvex) - MCL = 0.01 mg/l. In general, granular activated carbon or powdered activated carbon used in conjunction with coagulation and filtration, are the only treatment methods capable of significant removals. Other treatment methods such as coagulation/filtration, chlorination, ozonation, and addition of potassium permanganate remove, in general, less than 10 percent of the organics. The percentage removals which various treatment methods achieve, are shown in Table 6. Where blanks occur in this table, information is not presently available.

For total trihalomethanes, removal of the pre-cursor organic compounds by use of granular activated carbon has been determined to be the best treatment technique. Other techniques which will partially remove some of the naturally occurring pre-cursors are precipitation, oxidation, aeration, and adsorption on synthetic resins.

RADIUM - MCL = 5 pCi/l

Radium may occur naturally in water either as radium - 226 or radium - 228, and is generally found in ground water rather than surface water. Radium exists in radium-bearing rock strata, particularly in Iowa and Illinois, and in phosphate-rock deposits found in parts of Florida. Leaching from such deposits has resulted in high ground water concentrations.

The lime-soda softening process removes radium as well as hardness. Operationally, the total hardness removal necessary is equal to the fraction of radium removed, raised to the 2.86 power. In equation form:

$$\text{Hardness Removal Fraction} = (\text{Radium Removal Fraction})^{2.86}$$

or

$$\text{Radium Removal Fraction} = \sqrt[2.86]{\text{Hardness Removal Fraction}}$$

Therefore, to reduce 25 pCi/l to the 5 pCi/l MCL, requires a radium removal fraction of $0.8^{2.86} = 0.528$, meaning that 52.8 percent of the hardness must be removed. If desired hardness levels are met by blending, consideration must also be given to the influence of this blending on the radium concentration in the final blend. In situations with a relatively low hardness and high radium concentration, radium may control the blending ratio. Radium removal increases as pH increases.

Ion exchange and reverse osmosis are each capable of removing up to 95 percent of the input radium. Therefore the limiting concentration which can be treated to meet the MCL is 100 pCi/l.

SELENIUM - MCL = 0.01 mg/l

Selenium is chemically similar to sulfur, and commonly occurs with sulfur in mineral veins. Selenium in water may be in either the quadravalent (+4) form known as selenite ($SeO_3^{-2}$) or the hexavalent (+6) form known as

## TABLE 6

## PERCENT REMOVAL OF PESTICIDES BY WATER TREATMENT PROCESSES

| Treatment Method | Endrin | Lindane | Toxaphene | 2,4-D Sodium Salt | 2,4-D Isopropyl ester | 2,4-D Butyl ester | 2,4-D Isooctyl ester |
|---|---|---|---|---|---|---|---|
| Coagulation, filtration | 35 | <10 | <10 | <10 | <10 | <10 | <10 |
| Coagulation, filtration and adsorption with: | | | | | | | |
| Powdered activated carbon, mg/1 | | | | | | | |
| 5-9 | 85 | 30 | 93 | | | | |
| 10-19 | 80 | 55 | | | 90 | 90 | 90 |
| 20-29 | 94 | 80-90 | | | | | |
| 30- 9 | | | | 90 | | | |
| 40-49 | | | | | 97 | 97 | |
| 50-59 | 98 | | | | | | 97 |
| 70-79 | | 99 | | | 98 | | |
| Granular activated carbon, 5-7 - minute full bed contact time | >99 | >99 | | | | | |
| Oxidation: | | | | | | | |
| Chlorine, mg/1 | | | | | | | |
| 5 | <10 | <10 | | | | | |
| 8 | | <10 | | | | | |
| 50 | | <10 | | | | | |
| 100 | | | <10 | <10 | <10 | <10 | <10 |
| Ozone, mg/1 | | | | | | | |
| 11 | | <10 | | | | | |
| 38 | | 55 | | | | | |
| Potassium permanganate, mg/1 | | | | | | | |
| 10 | | <10 | | <10 | <10 | <10 | <10 |
| 40 | | <10 | | | | | |

Note: Treatment information not available for methoxychlor and 2,4,5-TP (Silvex) selenate ($SeO_4^{-2}$). The quadravalent form may be found in ground water, while the hexavalent form may occur in either ground water or surface water. Selenium contributions from natural sources are from selenium containing soils and runoff from these soils. Industrial related contributions may result from paint, rubber, dye, insecticide, glass, and electronic manufacturing.

Quadravalent (+4) Selenium

Adjustment of pH to 6.0 and coagulation with 30 mg/l ferric sulfate will treat raw waters containing up to 0.05 mg/l of $Se^{+4}$ to meet the 0.01 mg/l MCL, when followed by the clarification treatment described for moderate turbidity waters.

Raw waters containing up to 0.33 mg/l of $Se^{+4}$ can be treated by ion exchange or reverse osmosis. Lower concentrations may be treated to less than the MCL and then be utilized for blending purposes.

Hexavalent (+6) Selenium

Raw waters containing up to 0.33 mg/l of $Se^{+6}$ can be treated by ion exchange or reverse osmosis. As for the quadravalent form, lower concentrations may be reduced to less than the MCL, and then be utilized for blending.

SILVER - MCL = 0.05 mg/l

Silver rarely occurs in water supplies from natural sources, and many silver salts such as the chloride and sulfide forms are relatively insoluble. Generally speaking, silver contamination of water supplies is industrial in origin, from photographic and electroplating industries.

Coagulation in the pH range of 6 to 8 with 30 mg/l of alum or ferric sulfate will treat raw waters containing up to 0.17 mg/l of silver to meet the MCL of 0.05 mg/l, when followed by the clarification treatment described for moderate turbidity waters.

Coincidental removal occurs during the treatment of high coliform waters and moderate or high turbidity waters, provided that the dosage of ferric chloride or alum is adequate. In the pH range of 6 to 8, concentrations of 0.17 mg/l can be reduced to the MCL.

Lime softening followed by chemical clarification and filtration will also remove silver. Raw water silver concentrations of 0.17 mg/l can be treated at pH 9 while values as high as 0.5 mg/l can be reduced to the MCL of 0.05 at pH = 11.5.

Reverse osmosis may be used to remove silver, and concentrations up to 0.83 mg/l can be reduced to the MCL.

**SODIUM** - No Primary or Secondary Regulation MCL

Sodium occurs naturally in water supplies as a result of leaching from rock formations or naturally occurring salt deposits. Sea water intrusion may represent a sodium source in coastal areas. Sodium is extremely soluble, and rarely forms a precipitate.

Although there is presently no established sodium standard, a concentration of 20 mg/l of sodium in drinking water is considered compatible with a restricted sodium diet of 500 mg per day. Being a very soluble ion, removal is best accomplished by ion exchange or reverse osmosis. Ion exchange can remove up to 85 percent, restricting use to supplies with an initial sodium concentration of 133 mg/l. Reverse osmosis can offer somewhat larger removals, up to 93 percent, and thus could treat initial sodium concentrations up to 285 mg/l.

**SULFATE** - Secondary Regulation MCL = 250 mg/l

Sulfate is an extremely soluble anion which occurs in water supplies from both natural and industrial sources. Sulfate represents the principal form of sulfur in nature. Natural sources include leaching from soils and mineral deposits containing sulfate, and from the biological oxidation of sulfides. Rainfall in many areas is a major contributor of sulfate. Key industrial sources include sulfuric acid and sulfate manufacture and industries using sulfates and sulfuric acid, such as sulfate pulp mills and tanneries.

Research indicates that a limit of 250 mg/l of sulfate in drinking water affords a reasonable factor of safety against water causing laxative effects. As with sodium, ion exchange and reverse osmosis are the only practical treatment methods. Ion exchange can give removals up to 97 percent, and is therefore useful to concentrations as high as 8,330 mg/l. Reverse osmosis, however, will only remove 93 percent of the sulfate, and is therefore useful only up to 3,570 mg/l of sodium.

**TURBIDITY** - MCL = 1 to 5 TU, depending on several circumstances

Turbidity is produced by suspended and colloidal matter in water and is generally only a problem in surface water supplies. The principal importance of turbidity is the possible interference with disinfection, due to shielding of microbial contaminants, and the inability to maintain a disinfectant residual in the water supply. Aesthetic considerations are also important at high turbidity levels.

Low Turbidity Waters

Waters containing more than one TU (turbidity unit) but less than 25 TU should be treated by coagulation without settling, filtration at 41.4 to 203.5 Lpd/sq.M (2 to 5 gpm/sf), and post-disinfection with 30 minutes contact prior to use.

## Moderate Turbidity Waters

Water containing more than 25 but less than 1,000 TU should be treated by chemical addition, mixing, coagulation, 30 minutes flocculation, settling at basin overflow rates of 24,450 Lpd/sq.M (600 gpd/sf), filtration at 81.4 to 203.4 Lpd/sq.M (2 to 5 gpm/sf), and post-chlorination with 30 minutes contact prior to use.

## High Turbidity Waters

Waters containing more than 1,000 TU and meeting the Interim Regulations in other respects should be subjected to 2 hours pre-sedimentation at basin overflow rates of 142,600 Lpd/sq.M (3,500 gpd/sf), followed by the treatment provided for moderate turbidity waters, above.

## V. COST CURVES

### A. Construction Cost Curves

The construction cost curves were developed using equipment cost data supplied by manufacturers, cost data from actual plant construction, unit takeoffs from actual and conceptual designs, and published data. The cost curves were then checked and verified by a second consulting engineering firm, using an approach similar to that which would be utilized by a general contractor in determining his construction bid. Every attempt has been made to present the conceptual designs and assumptions which were incorporated into the curves. Adjustment of the curves may be necessary to reflect site specific conditions, geographic or local conditions, or the need for standby power. The curves should be particularly useful for estimating the relative economics of alternative treatment systems and in the preliminary evaluation of general cost level to be expected for a proposed project. The curves contained in this Interim Report are based on January, 1978, costs.

The construction cost was developed by determining and then aggregating the cost of the following eight principal components: (1) Excavation and Site Work; (2) Manufactured Equipment; (3) Concrete; (4) Steel; (5) Labor; (6) Pipe and Valves; (7) Electrical and Instrumentation; and (8) Housing. These eight categories were utilized primarily to facilitate accurate cost updating, which is discussed in a subsequent section of this Interim Report. The division will also be helpful where costs are being adjusted for site specific, geographic and other special conditions. The eight categories include the following general items:

> Excavation and Site Work. This category includes work related only to the applicable process and does not include any general site work such as sidewalks, roads, driveways, or landscaping.
>
> Manufactured Equipment. This category includes estimated purchase cost of pumps, drives, process equipment, specific purpose controls and other items which are factory made and sold with equipment.
>
> Concrete. This category includes the delivered cost of ready mix concrete and concrete forming materials.
>
> Steel. This category includes reinforcing steel for concrete and miscellaneous steel not included within the Manufactured Equipment category.

Labor. The labor associated with installing manufactured equipment, piping and valves, constructing concrete forms and placing concrete and reinforcing steel, are included in this category.

Pipe and Valves. Cast iron pipe, steel pipe, valves, and fittings have been combined into a single category. The purchase price of pipe, valves, fittings, and associated support devices are included within this category.

Electrical and Instrumentation. The cost of process electrical equipment, wiring and general instrumentation associated with the process equipment is included in this category.

Housing. In lieu of segregating building costs into several components this category represents all material and labor costs associated with the building, including heating, ventilating, air conditioning, lighting, normal convenience outlets, and the slab and foundation.

The subtotal of the costs of these eight categories includes the cost of material and equipment purchase and installation, and subcontractor's overhead and profit. To this subtotal, a 15 percent allowance has been added to cover miscellaneous items not included in the cost takeoff as well as contingency items. Experience at many water treatment facilities has indicated that this 15 percent allowance is reasonable. Although blanket application of this 15 percent allowance may result in some minor inequity between processes, during the combination of costs for individual processes into a treatment system, the inequities are generally balanced out.

The construction cost for each unit process is presented as a function of the most applicable design parameter for the process. For example, clarifier construction costs are presented versus square feet of surface area, whereas chlorine feed system costs are presented versus daily chlorine feed capacity. Use of such key design parameters allows the curves to be utilized with greater flexibility than if costs were simply plotted versus flow. For example, the clarifier curve is applicable to a 5 mgd flow regardless of whether regulatory agencies require, or designer preference indicates, use of a surface overflow rate of 700 gpd/ft$^2$ or 900 gpd/ft$^2$. For some processes, however, flow rate is the most applicable design parameter, a situation which is true for package plants.

The construction costs shown in the curves are not the final capital cost for the unit process. The construction cost curves do not include costs for special sitework, general contractor overhead and profit, engineering, land, legal, fiscal, and administrative and interest during construction. These cost items are all more directly related to the total cost of a project, rather than the cost of the individual unit processes. They therefore are most appropriately added following summation of the cost of the individual unit processes, if more than one unit process is required. Example calculations are included following the individual unit process cost curves to illustrate the recommended method for the addition of these costs.

## B. Operation and Maintenance Cost Curves

Operation and maintenance curves were developed for: (1) energy requirements, (2) maintenance material requirements, (3) labor requirements, and (4) total operation and maintenance cost. The requirements were determined from operating data at existing plants, at least to the extent possible. Where such information was not available, assumptions were made based both upon the author's and equipment manufacturer's experience, and such assumptions are stated in the description of the cost curve.

Energy requirements were developed for both process energy and building related energy, and are presented in terms of kilowatt-hours per year. This approach was used to allow ready adjustment for geographical influence upon building related energy. For example, while lighting requirements average about 17.5 kw-hr/ft$^2$/yr throughout the United States; heating, cooling, and ventilating requirements vary from a low of about 8 kw-hr/ft$^2$/yr in Miami, Florida to a high of about 202 kw-hr/ft$^2$/yr in Minneapolis, Minnesota. The electrical energy cost curves presented for each process are in terms of kw-hr/yr, and include an average building related demand of 102.6 kw-hr/ft$^2$/yr. This is an average for the 21 cities included in the Engineering News Record Indexes. An explanation of the derivation of this number is included in Appendix A. The computer program to be developed by the Final Report will allow other building related energy demands than 102.6 kw-hr/ft$^2$/yr. Process electrical energy is also included in the electrical energy curve, and was calculated using manufacturer's data for required components. Where required, separate energy curves for natural gas and diesel fuel are also presented.

Maintenance material costs include the cost of periodic replacement of component parts necessary to keep the process operable and functioning. Examples of maintenance material items included are valves, motors, instrumentation, and other process items of similar nature. The maintenance material requirements *do not include the cost of chemicals* required for process operation. *Chemical costs must be added separately*, as will be shown in the examples presented following the individual unit process cost curves.

The labor requirement curve includes both operation and maintenance labor, and is presented in terms of hours per year.

The total operation and maintenance cost curve is a composite of the energy, maintenance material, and labor curves. To determine annual energy costs, unit costs of \$0.03/kw-hr of electricity, \$0.0013/cubic foot of natural gas, and \$0.45/gallon of diesel fuel were utilized. The labor requirements were converted to an annual cost using an hourly labor rate of \$10.00/hour, which includes salary and fringe benefits. The computer program to be developed by the Final Report will allow utilization of other unit costs for energy and labor.

## C. Updating Costs to Time of Construction

Continued usefulness of the curves developed as a portion of this Project depends upon the ability of the curves to be updated to reflect inflationary increases in the prices of the various components. Most engineers and planners are accustomed to updating costs using one all encompassing index, which tracks the cost of specific items and then proportions the costs according to a predetermined ratio. The key advantage of a single index is the simplicity with which it can be applied. Although use of a single index is an uncomplicated approach, there is much evidence to indicate that these time honored indices are not understood by many users and/or are inadequate for application to water works construction.

The most frequently utilized single indexes in the construction industry are the Engineering News Record's Construction Cost Index (CCI) and Building Cost Index (BCI). These ENR indices were started in 1921 and were intended for general construction cost monitoring. The ENR Construction Cost Index consists of 200 hours of common labor, 2,500 pounds of structural steel shapes, 1.128 tons of Portland Cement and 1,008 board feet of 2 x 4 lumber. The ENR Building Cost Index consists of 68.38 hours of skilled labor plus the same materials included in the Construction Cost Index. The large amount of labor included in the Construction Cost Index was appropriate prior to World War II; however, on most contemporary construction, the index labor component is far in excess of actual labor used.

Although key advantages of the ENR indices include their availability, their simplicity and their geographical specificity, many engineers and planners believe that these indices are not applicable to water treatment plant construction. The rationale for this belief is that the index does not include mechanical equipment, pipes, and valves which are normally associated with such construction, and the proportional mix of materials and labor is not specific to water treatment plant construction.

An approach which may be utilized to overcome the shortcomings of the ENR indices relative to water works construction, is to apply specific indices to the major cost components of the construction cost curves. This approach allows the curve to be updated using indexes specific to each category and weighted according to the dollar significance of the category. For the eight major categories of construction cost, the following Bureau of Labor Statistics (BLS) and Engineering News Record (ENR) indices were utilized as a basis for the cost curves included in this Interim Report.

| Cost Component | Index | January, 1978 Value of Index |
|---|---|---|
| Excavation and Sitework | ENR Skilled Labor Wage Index (1967 Base) | 235 |
| Manufactured Equipment | BLS General Purpose Machinery and Equipment - Code 114 | 208.6 |
| Concrete | BLS Concrete Ingredients - Code 132 | 208.6 |
| Steel | BLS Steel Mill Products - Code 1013 | 237.5 |

| Cost Component | Index | January, 1978 Value of Index |
|---|---|---|
| Labor | ENR Skilled Labor Wage Index (1967 Base) | 235 |
| Pipe and Valves | BLS Valves and Fittings Code 114901 | 222.4 |
| Electrical and Instrumentation | BLS Electrical Machinery and Equipment - Code 117 | 160.0 |
| Housing | ENR Building Cost Index (1967 Base) | 237.88 |

The principal disadvantages of this approach are the lack of geographical specificity of the BLS indices, and the use of seven indices rather than a single index.

To accomodate these two different approaches to cost updating, the cost curves were derived by developing the cost of the eight component areas, and then aggregating the eight components. This approach allows costs to be updated by using indices specific to the eight cost component categories, or by applying the ENR Construction Cost Index to the sum cost.

Updating of total operation and maintenance costs may be accomplished by updating the three individual components: energy, labor, and maintenance material. Energy and labor are updated by applying the current unit cost to the energy and labor curves. Maintenance material costs, which are presented in terms of dollars per year, can be updated using the Producer Price Index, which replaces the old Wholesale Price Index. The maintenance material costs in this Interim Report are for January, 1978, a Producer Price Index of 186.8

## CONSTRUCTION COST

### Package Pressure Filtration Plants

Package pressure filters can be used for iron and manganese removal from well waters, and in some States as a final treatment process following chemical coagulation and clarification of surface waters. Pressure filters are available from many manufacturers with either rapid sand, dual media or mixed media filter beds. Units can be either totally automatic or manual in operation.

Construction costs were developed for package pressure filtration plants of capacities ranging between 1,000 gpd and 0.5 mgd, for filtration rates of 2 and 5 gpm/square foot and a media depth of 30 inches. Conceptual designs for the plants are shown in Table 7. Vessel sizes selected are those generally available in the industry. Costs are based upon completely housed filtration plants.

All units are skid mounted, completely self-contained and include a single vertical pressure vessel with internals, automatic control valves, filter supply pump, filter media (mixed), backwash pump and control panel. Included with each unit are two chemical feed units including tank, mixer and chemical feed pump. Finished water is discharged to an at grade storage tank/ clearwell which is not included in the cost estimate.

Backwash water is pumped from the storage tank by an end suction centrifugal pump. The filter supply pump is also an end suction centrifugal pump and requires a flooded suction. The filter units are designed for automatic operation. Backwash is initiated by excessive headloss or by elapsed operating time. Surface wash is obtained from a separate pump or from a pressure distribution system through a backflow preventer.

Estimated construction costs are presented in Table 8 and illustrated in Figure 1.

## OPERATION AND MAINTENANCE COSTS

### Package Pressure Filtration Plants

Operating and maintenance costs have been developed from estimates of energy, labor and maintenance material requirements for the conceptual designs presented in Table 7. Building energy requirements are for heating, cooling, ventilation and lighting. Process energy, which is not nearly as large as building related energy, is for backwash and filter supply pumping and the chemical feeders.

Maintenance material requirements are related primarily to replacement of pump seals, application of lubricants, replacement of parts for chemical feed pumps, instrumentation repair and general facility maintenance supplies. The maintenance material costs do not include the cost of treatment chemicals.

## Table 7

## Conceptual Design

## Package Pressure Filtration Plants

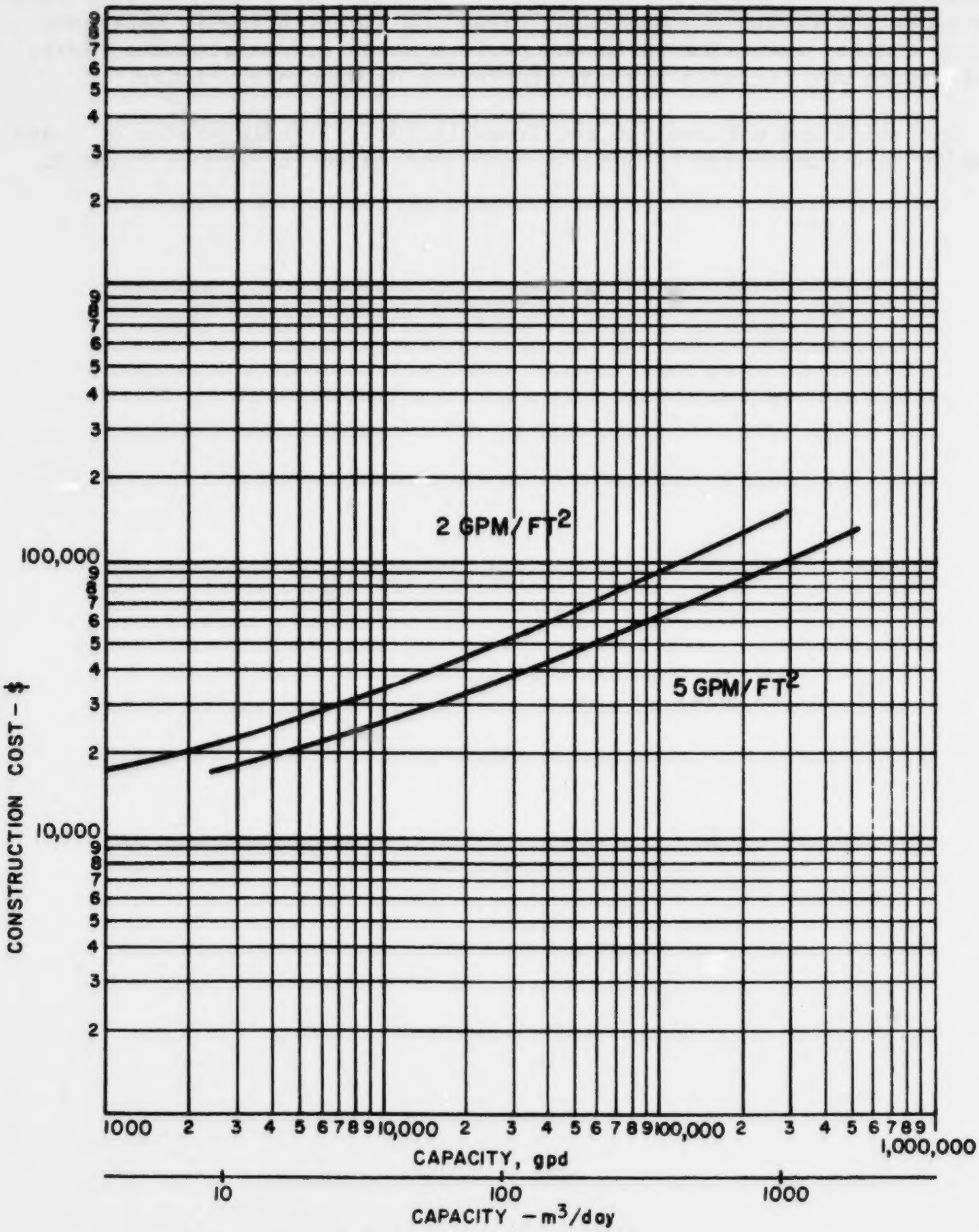
| Plant Capacity - gpd |  | Filter Vessels |  |  | Total Filter Area, ft$^2$ | Housing Area, ft$^2$ |
|---|---|---|---|---|---|---|
| 2 gpm/ft$^2$ | 5 gpm/ft$^2$ | Number of Units | Filter Area, ft$^2$ | Diameter ft |  |  |
| 1,000 | 2,500 | 1 | 0.34 | 0.67 | 0.34 | 240 |
| 10,000 | 25,000 | 1 | 3.14 | 2 | 3.14 | 300 |
| 40,000 | 100,000 | 1 | 12.6 | 4 | 12.6 | 480 |
| 100,000 | 250,000 | 1 | 34.2 | 6.5 | 34.2 | 896 |
| 200,000 | 500,000 | 1 | 64 | 9 | 64 | 1,080 |

## Table 8

## Construction Cost

## Package Pressure Filtration Plants

| | Plant Capacity - gpd | | | | |
|---|---|---|---|---|---|
| 2 gpm/ft$^2$ | 1,000 | 10,000 | 40,000 | 100,000 | 200,000 |
| 5 gpm/ft$^2$ | 2,500 | 25,000 | 100,000 | 250,000 | 500,000 |
| Excavation and Sitework | $ 100 | 100 | 125 | 200 | 220 |
| Manufactured Equipment | 4,380 | 15,250 | 23,125 | 36,870 | 55,000 |
| Concrete | 360 | 440 | 650 | 1,100 | 1,300 |
| Labor | 1,310 | 4,570 | 6,940 | 11,060 | 16,500 |
| Piping and Valves | 500 | 600 | 850 | 1,100 | 1,400 |
| Electrical and Instrumentation | 1,700 | 4,040 | 6,180 | 10,200 | 14,300 |
| Housing | 7,200 | 9,000 | 14,400 | 26,880 | 32,400 |
| SUBTOTAL | 15,550 | 34,000 | 52,270 | 87,410 | 121,120 |
| Miscellaneous and Contingency | 2,330 | 5,100 | 7,840 | 13,110 | 18,170 |
| TOTAL | $17,880 | 39,100 | 60,110 | 100,520 | 139,290 |



CONSTRUCTION COST
PACKAGE PRESSURE FILTRATION PLANTS

FIGURE 1

Labor requirements were developed assuming the treatment plant operates automatically, and virtually unattended. Operator attention is only necessary to prepare the treatment chemicals, establish proper dosages, carry out routine quality assurance tasks and perform necessary maintenance tasks. No allowance was included for administrative or laboratory labor.

Operation and maintenance requirements for filtration rates of 2 and 5 $gpm/ft^2$ are summarized in Table 9 and illustrated in Figures 2 and 3.

## Table 9

## Operation and Maintenance Summary

## Package Pressure Filtration Plants

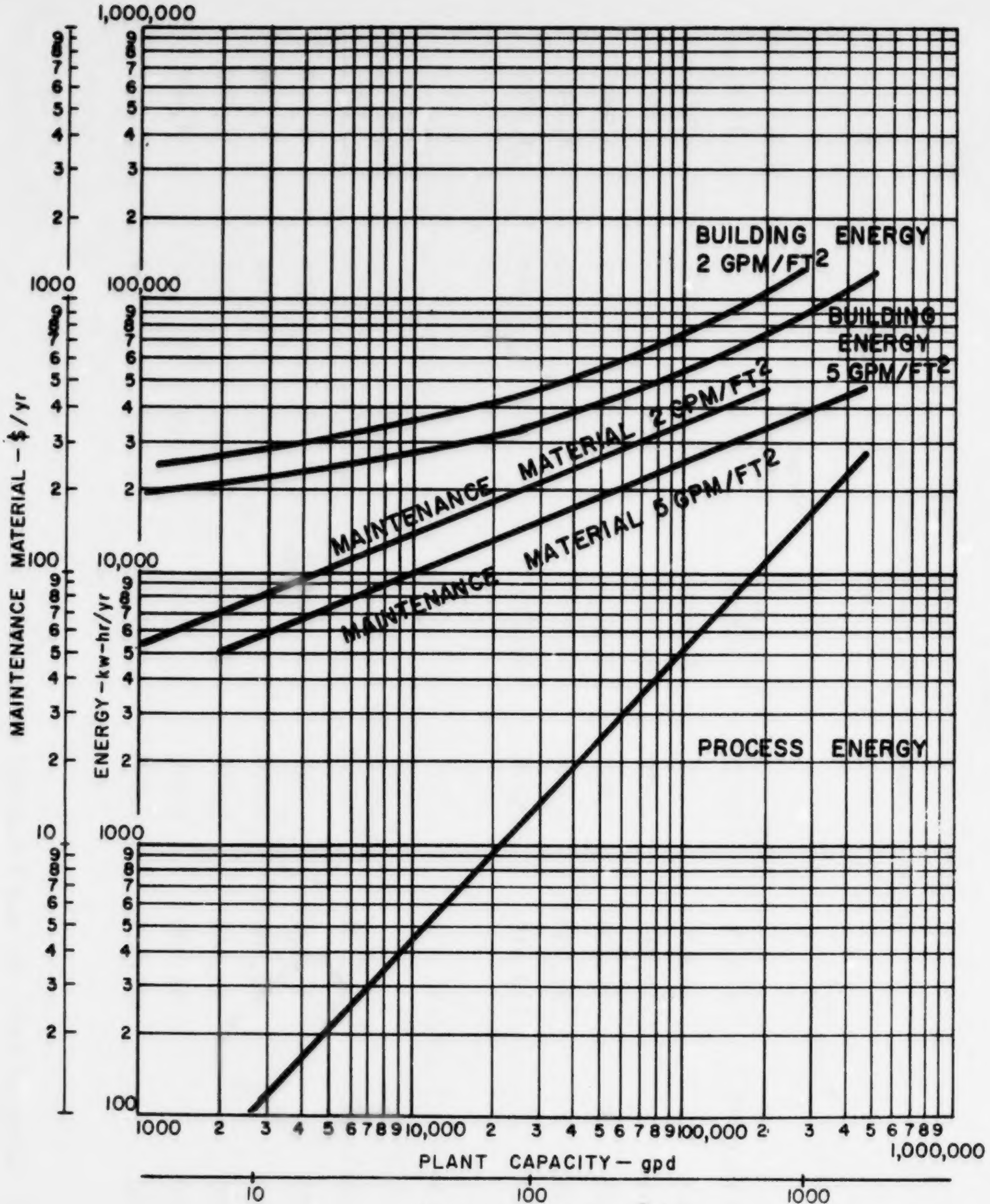
Filtration Rate = 2 gpm/ft$^2$

| Plant Capacity, gpd | Energy kw-hr/yr Building | Energy kw-hr/yr Process | Energy kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 1,000 | 24,620 | 50 | 24,670 | 50 | 365 | 4,440 |
| 10,000 | 30,780 | 450 | 31,230 | 150 | 365 | 4,740 |
| 40,000 | 49,250 | 1,830 | 51,080 | 200 | 425 | 5,980 |
| 100,000 | 91,930 | 4,950 | 96,880 | 350 | 500 | 8,260 |
| 200,000 | 110,810 | 9,270 | 120,080 | 450 | 730 | 11,350 |

Filtration Rate = 5 gpm/ft$^2$

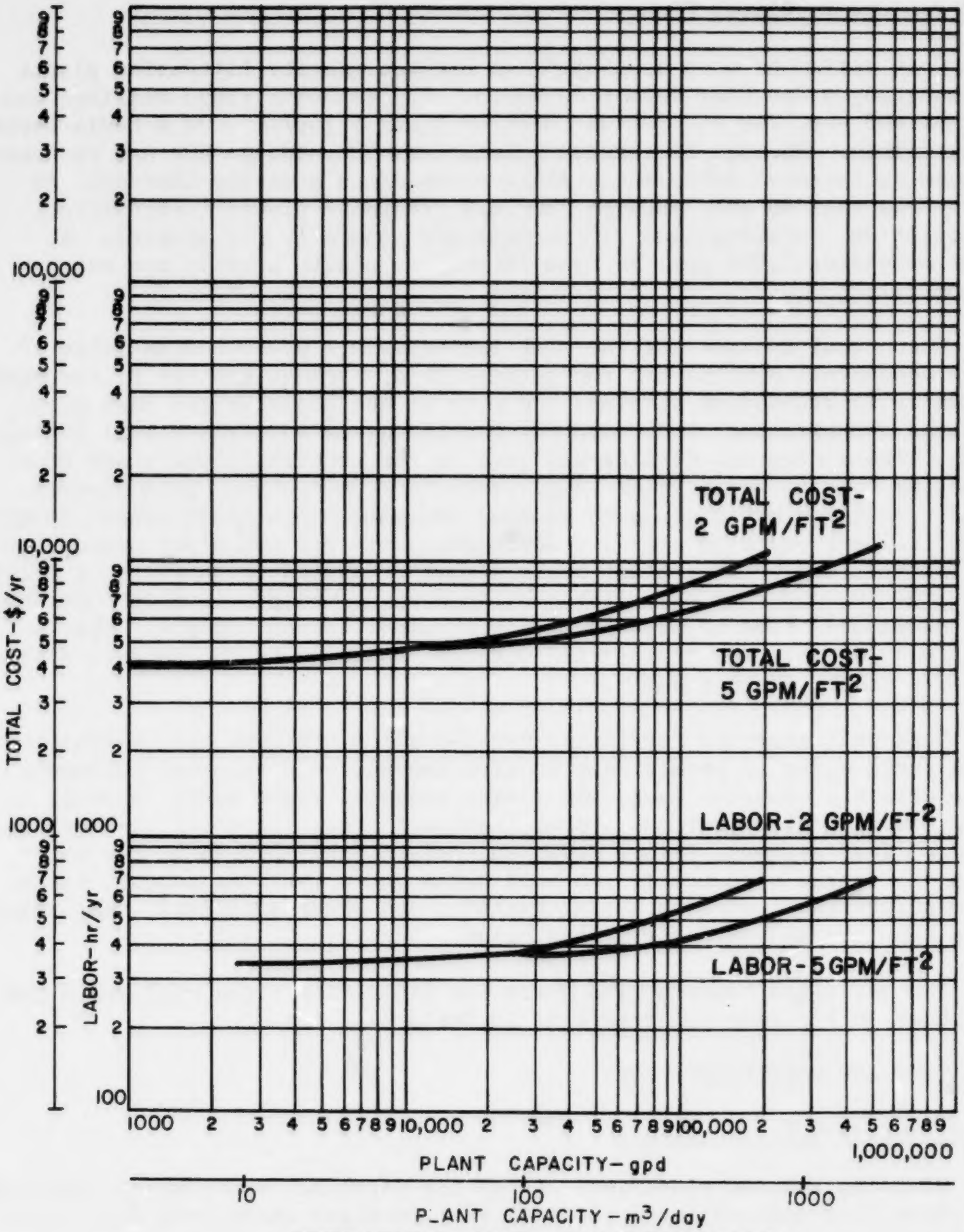
| Plant Capacity, gpd | Energy kw-hr/yr Building | Energy kw-hr/yr Process | Energy kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 2,500 | 24,620 | 120 | 24,740 | 50 | 365 | 4,440 |
| 25,000 | 30,780 | 1,220 | 32,000 | 150 | 365 | 4,760 |
| 100,000 | 49,250 | 5,040 | 54,290 | 200 | 425 | 6,080 |
| 250,000 | 91,930 | 9,820 | 101,750 | 350 | 500 | 8,400 |
| 500,000 | 110,810 | 24,550 | 135,360 | 450 | 730 | 11,810 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
PACKAGE PRESSURE FILTRATION PLANTS

FIGURE 2



OPERATION AND MAINTENANCE
PACKAGE PRESSURE FILTRATION PLANTS

FIGURE 3

## CONSTRUCTION COST

### Package Gravity Filter Plants

Cost estimates were developed for package gravity filtration plants preceeded by a one hour detention basin. The capacity range utilized was 80 to 1,400 gpm, for filtration rates of 2 and 5 gpm/ft$^2$ and a media depth of 30 inches. Package filtration plants less than 80 gpm are not recommended because operational skill and attention are often severely limited. At flows less than 80 gpm, package complete treatment plants (coagulation, flocculation, settling, and filtration) are generally recommended. At flows exceeding 1,400 gpm, package filtration plants usually are not economical.

Conceptual designs for the cost estimates are presented in Table 10. These conceptual designs are representative of package gravity filter plants currently in widespread service, and much of the construction cost data utilized was obtained from equipment manufacturers and from actual installations. The conceptual designs analyzed in the report include a one hour detention control basin prior to filtration. The contact basin removes rapidly settling materials such as sand and silt which could hamper operation of the filters and also provides additional time for coagulant dispersion and flocculation. The contact basin serves to dampen the effects on coagulant requirements caused by raw water quality changes and provides the operator with additional time to make necessary chemical dosage changes. The efficiency of chlorine disinfection is also enhanced by the detention time provided in the contact basin.

Cost estimates are for filter vessels which are open top, cylindrical steel tanks sized to permit shop fabrication and over-the-road shipment. The plants are complete including filter vessels, mixed media, piping, valves, controls, electrical system, backwash system, surface wash system, chemical feed systems, (alum, soda ash, polymer and chlorine), raw water pumps (no intake structure), one hour detention pre-filter contact basin, backwash/clearwell storage basin, building and other ancillary items required for a complete and operable installation.

The estimated construction costs for filtration rates of 2 and 5 gpm/ft$^2$ are shown in Figure 4 and presented in Table 11.

## OPERATION AND MAINTENANCE COST

### Package Gravity Filter Plants

Building related electrical energy for lighting, ventilation, heating and other uses was projected for each size facility based upon floor area of the structure. In all cases the filters, piping, controls, chemical feed equipment and other mechanical appurtenances are entirely enclosed. Process related energy is for filter supply pumping, filter backwash and filter surface wash.

## Table 10

## Conceptual Design

## Package Gravity Filter Plants

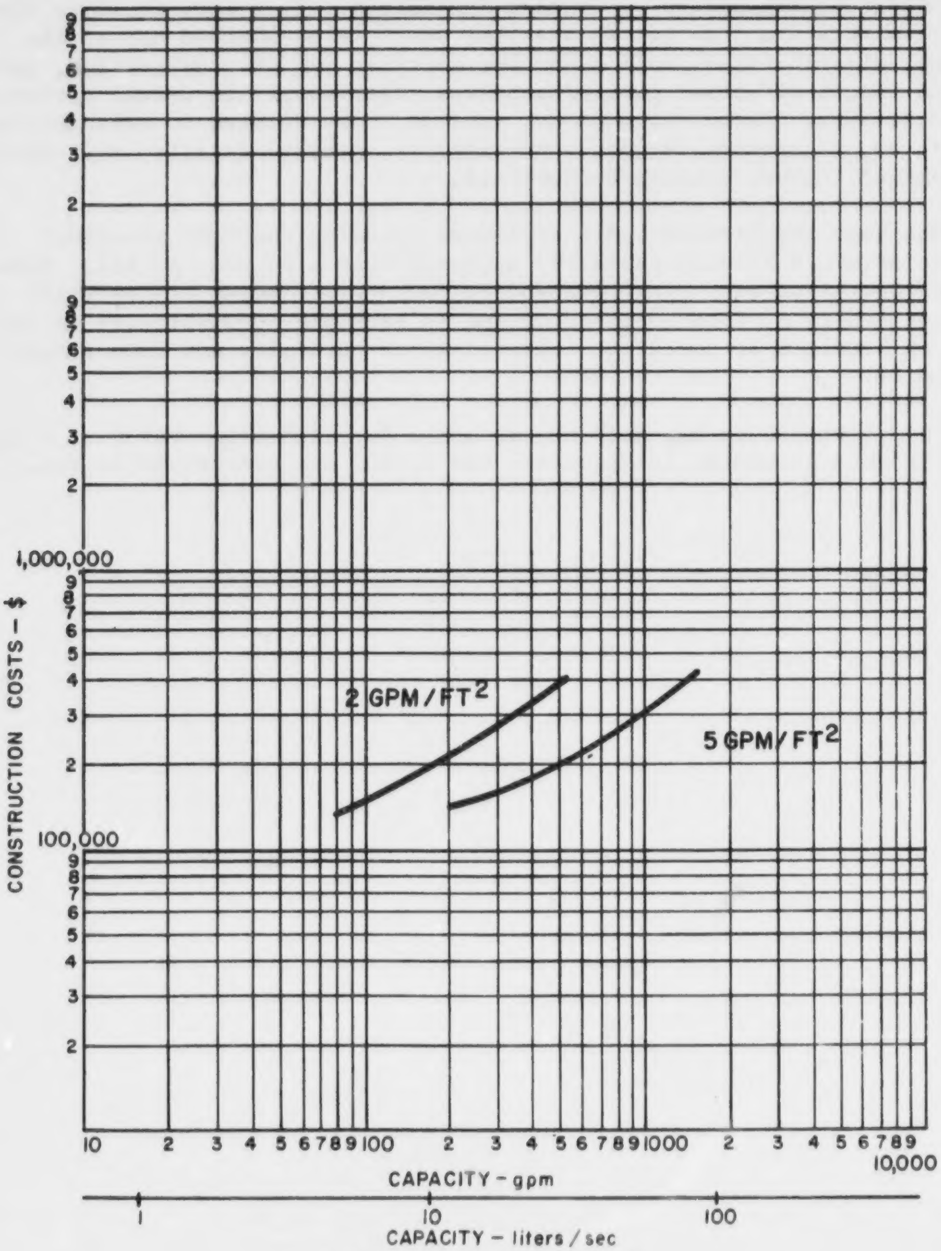
| Plant Capacity, gpm | | Filter Vessels | | | | |
|---|---|---|---|---|---|---|
| 2 gpm/ft$^2$ | 5 gpm/ft$^2$ | Number of Units | Filter Area ft$^2$ | Diameter ft | Total Filter Area, ft$^2$ | Housing Area, ft$^2$ |
| 80 | 200 | 2 | 20 | 5 | 40 | 1,500 |
| 140 | 350 | 2 | 38 | 7 | 76 | 1,800 |
| 225 | 560 | 2 | 50 | 8 | 100 | 1,800 |
| 280 | 700 | 2 | 79 | 10 | 158 | 1,800 |
| 560 | 1,400 | 3 | 113 | 12 | 339 | 3,600 |

### Table 11

### Construction Cost

### Package Gravity Filter Plants

| | Plant Flow Rate - gpm | | | | |
|---|---|---|---|---|---|
| 2 gpm/ft$^2$ | 80 | 140 | 225 | 280 | 560 |
| 5 gpm/ft$^2$ | 200 | 350 | 560 | 700 | 1,400 |
| Excavation and Sitework | $ 790 | 1,080 | 1,440 | 1,580 | 2,660 |
| Manufactured Equipment | 27,000 | 35,000 | 38,000 | 50,000 | 90,000 |
| Concrete | 14,000 | 19,500 | 26,500 | 29,000 | 47,500 |
| Labor | 11,230 | 12,690 | 13,630 | 16,450 | 25,730 |
| Pipe and Valves | 6,460 | 8,380 | 11,110 | 11,650 | 25,280 |
| Electrical and Instrumentation | 19,500 | 24,900 | 31,000 | 46,400 | 81,000 |
| Housing | 45,000 | 54,000 | 54,000 | 54,000 | 108,000 |
| SUBTOTAL | 123,980 | 155,550 | 175,680 | 209,080 | 380,170 |
| Miscellaneous and Contingency | 18,600 | 23,330 | 26,350 | 31,360 | 57,030 |
| TOTAL | $142,580 | 178,880 | 202,030 | 240,440 | 437,200 |



CONSTRUCTION COST
PACKAGE GRAVITY FILTER PLANTS

FIGURE 4

The cost of maintenance material was estimated from background information obtained from several operating facilities. This item includes the cost of anthracite coal to replace that which is backwashed out of the filters, miscellaneous small parts for controls and instrumentation, recorder ink and charts and other general supplies related only to actual operation of the filters. These costs do not include those related to administrative activities, laboratory chemicals or supplies, general facility maintenance nor do they include treatment chemicals.

Man hour requirements were developed assuming that the treatment facilities would be only partially attended over a 24 hour period. This mode of operation is typical for modern package treatment plants which are designed to perform unattended, and to backwash automatically on the basis of headloss or excessive filtered water turbidity and then return to service.

Operation and maintenance requirements for filtration rates of 2 and 5 gpm/ft$^2$ are presented in Figures 5 and 6, and are summarized in Table 12.

## Table 12

## Operation and Maintenance Summary

## Package Gravity Filter Plants

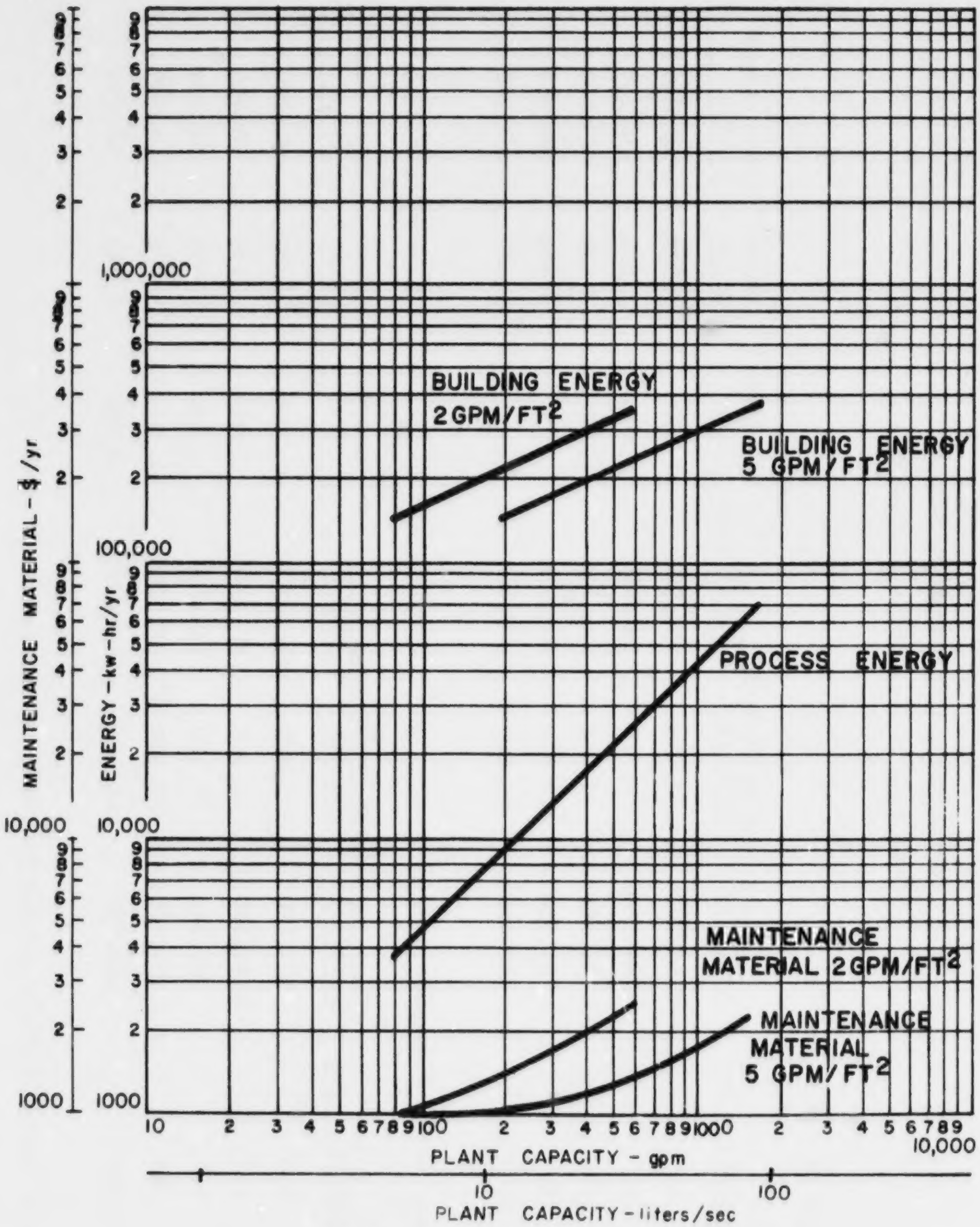
Filtration Rate = 2 gpm/ft$^2$

| Plant Capacity - gpm | Energy kw-hr/yr Building | Energy kw-hr/yr Process | Energy kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 80 | 153,900 | 3,950 | 157,850 | 1,000 | 2,920 | 34,940 |
| 140 | 184,680 | 6,920 | 191,600 | 1,200 | 2,920 | 36,150 |
| 225 | 184,680 | 11,064 | 195,740 | 1,300 | 3,650 | 43,670 |
| 280 | 184,680 | 13,830 | 198,510 | 1,500 | 3,650 | 43,960 |
| 560 | 360,000 | 27,660 | 387,660 | 2,500 | 4,380 | 57,930 |

Filtration Rate = 5 gpm/ft$^2$

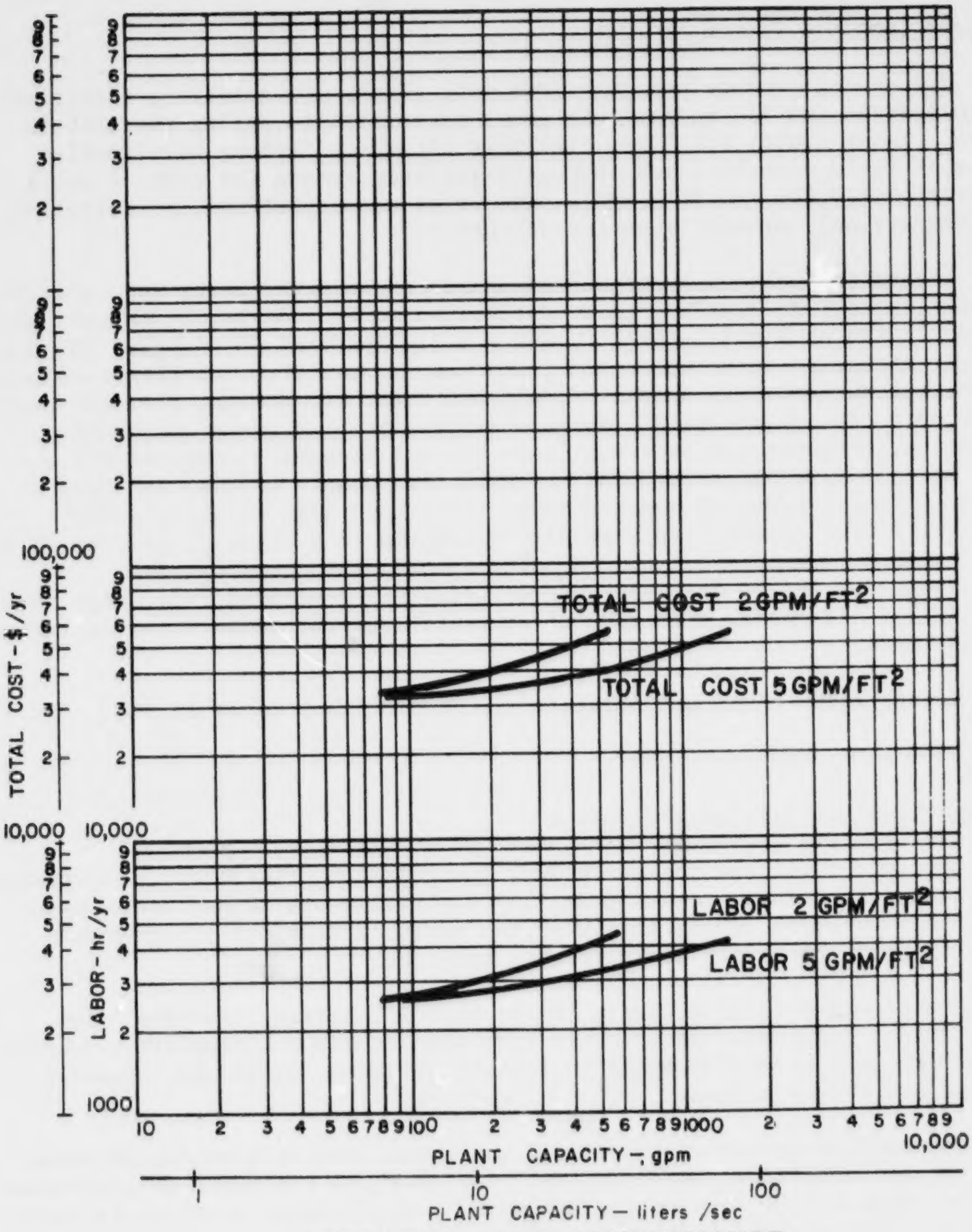
| Plant Capacity - gpm | Energy kw-hr/yr Building | Energy kw-hr/yr Process | Energy kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 200 | 153,900 | 9,470 | 163,370 | 1,000 | 2,920 | 35,100 |
| 350 | 184,680 | 16,580 | 201,260 | 1,200 | 2,920 | 36,440 |
| 560 | 184,680 | 26,250 | 210,930 | 1,300 | 3,650 | 44,130 |
| 700 | 184,680 | 33,150 | 217,830 | 1,500 | 3,650 | 44,530 |
| 1,400 | 360,000 | 66,300 | 426,300 | 2,500 | 4,380 | 59,090 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
PACKAGE GRAVITY FILTER PLANTS

FIGURE 5



OPERATION AND MAINTENANCE
PACKAGE GRAVITY FILTER PLANTS

FIGURE 6

## CONSTRUCTION COST

### Package Complete Treatment Plants

The use of package complete treatment plants (coagulation, flocculation, sedimentation and filtration) has grown substantially during the last 10 years. These plants which are available either as factory preassembled units or field assembled modules, significantly reduce the cost of small facilities (10,000 gpd to 2 mgd). The units are automatically controlled and require only minimal operator attention.

Cost estimates were developed for standard manufactured units incorporating 20 minutes of flocculation, tube settlers rated at 150 gpd/ft$^2$, mixed media filters rated at 2 and 5 gpm/ft$^2$, and a media depth of 30 inches. The costs include premanufactured treatment plant components, chemical feed facilities (storage tanks and feed pumps), flow measurement and control devices, pneumatic air supply (for plants of 200 gpm and larger) for valve and instrument operation, effluent and backwash pumps and all necessary controls for a complete and operable unit. The three smaller plants utilize low head filter effluent transfer pumps and are to be used with an above grade clearwell. The larger plants gravity discharge to a below grade clearwell.

Raw water intake and pumping facilities, clearwell storage, high service pumping and site work, exclusive of foundation preparations, are not included in the costs.

Construction costs are presented in Figure 7 and Table 13.

## OPERATION AND MAINTENANCE COST

### Package Complete Treatment Plants

Complete treatment package plants (coagulation, flocculation, sedimentation, and filtration) are designed for essentially unattended operation, i.e., they backwash automatically on the basis of headloss or excessive filtered water turbidity and return to service.

The principal use of energy is for building heating, cooling, and ventilation, and these requirements have been based on a completely housed plant. Process energy is required for flocculators, rapid mix, chemical pumping and filter backwash.

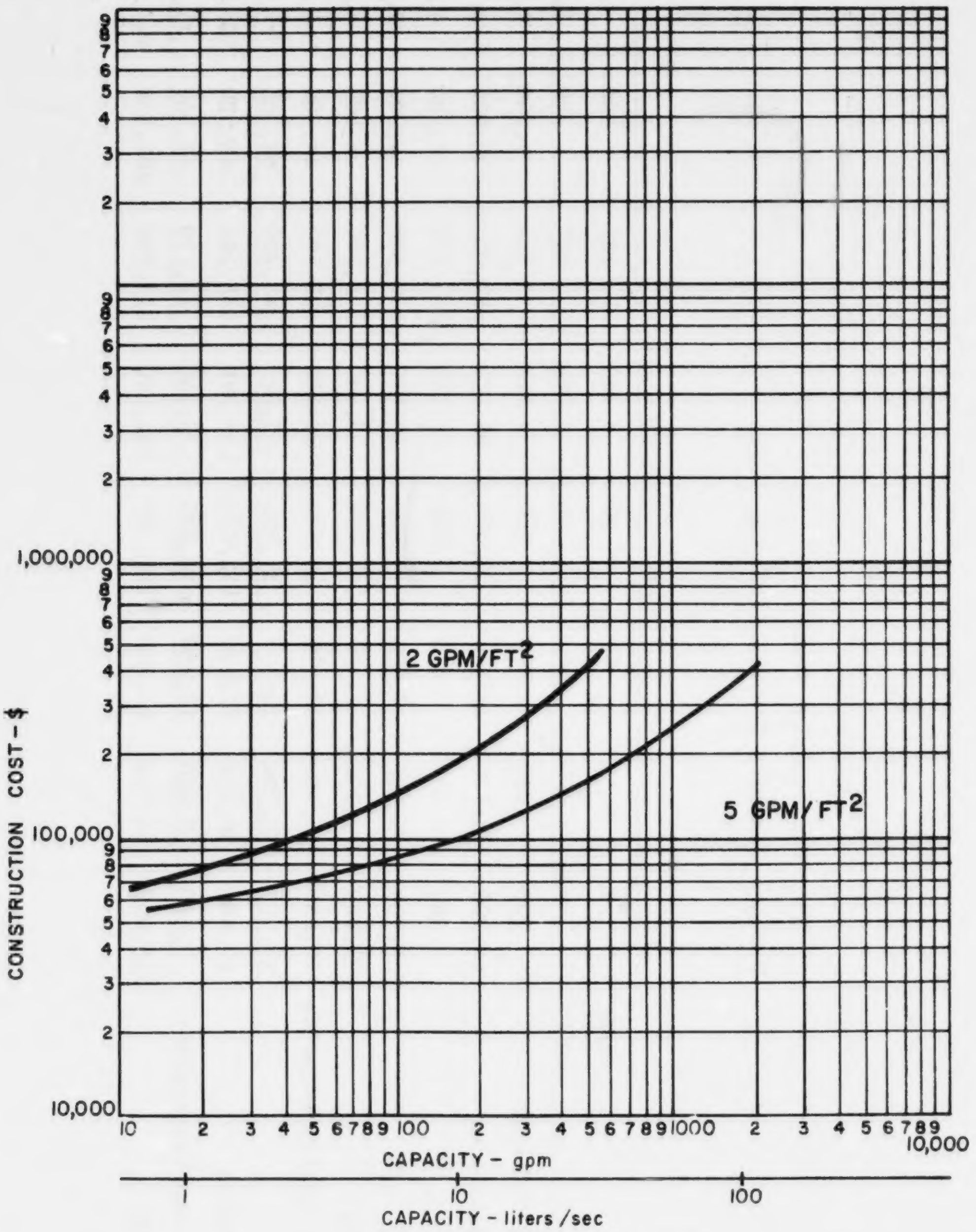
The cost of maintenance material was based upon information obtained from typical operating installations. Included are the costs of anthracite coal to replace that lost during backwash, miscellaneous small replacement parts for controls and instrumentation and other general supplies related to the operation of the treatment plant proper. Excluded are those costs related to treatment plant administrative activities, laboratory services, chemicals or other related supplies, and general facility maintenance.

## Table 13

### Construction Cost

### Package Complete Treatment Plants

| | Plant Capacity - gpm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2 gpm/ft$^2$ | 4 | 8 | 40 | 80 | 140 | 225 | 280 | 560 |
| 5 gpm/ft$^2$ | 10 | 20 | 100 | 200 | 350 | 560 | 700 | 1,400 |
| Excavation and Sitework | $ 200 | 260 | 370 | 520 | 770 | 800 | 1,250 | 2,100 |
| Manufactured Equipment | 12,300 | 15,400 | 29,000 | 50,000 | 68,000 | 84,000 | 100,000 | 175,000 |
| Concrete | 350 | 430 | 650 | 1,040 | 1,840 | 1,950 | 2,930 | 4,330 |
| Labor | 5,100 | 6,000 | 7,000 | 10,200 | 13,600 | 16,800 | 24,000 | 37,500 |
| Pipe and Valves | 1,000 | 1,100 | 1,500 | 2,800 | 3,400 | 4,100 | 5,600 | 8,700 |
| Electrical and Instrumentation | 15,630 | 16,780 | 20,610 | 20,610 | 25,780 | 28,790 | 46,900 | 64,200 |
| Housing | 14,900 | 16,300 | 20,300 | 27,300 | 45,600 | 47,700 | 68,300 | 97,000 |
| SUBTOTAL | 49,480 | 56,270 | 79,430 | 112,470 | 158,990 | 184,140 | 248,980 | 388,830 |
| Miscellaneous and Contingency | 7,420 | 8,440 | 11,910 | 16,870 | 23,850 | 27,620 | 37,350 | 58,320 |
| TOTAL | $56,900 | 64,710 | 91,340 | 129,340 | 182,840 | 211,760 | 286,330 | 447,150 |



CONSTRUCTION COST
PACKAGE COMPLETE TREATMENT PLANTS

FIGURE 7

Operator attention is required to replenish treatment chemicals, make proper chemical dosage requirements, perform routine laboratory quality assurance tests and carryout necessary daily maintenance and other house keeping tasks. Labor estimates were based on performance of these tasks.

Operation and maintenance requirements for plant filtration rates of 2 and 5 gpm/ft$^2$ are presented in Figures 8 and 9 and summarized in Table 14.

## Table 14

## Operation and Maintenance Summary

## Package Complete Treatment Plants

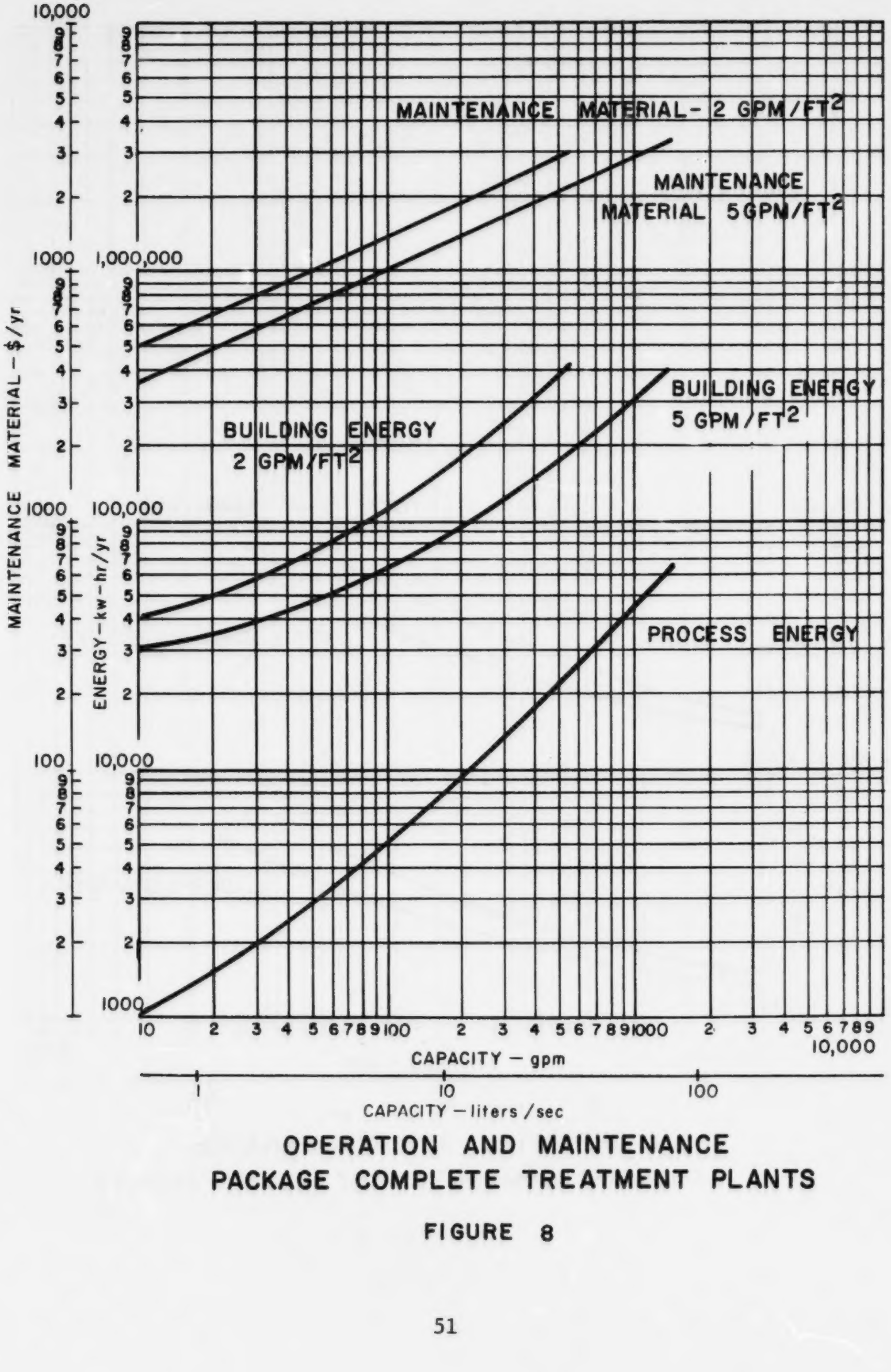
Filtration Rate = 2 gpm/ft$^2$

| Plant Capacity - gpm | Energy kw-hr/yr Building | Energy kw-hr/yr Process | Energy kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 4 | 30,780 | 320 | 31,100 | 300 | 1,460 | 15,830 |
| 8 | 38,480 | 390 | 38,870 | 550 | 1,460 | 16,320 |
| 40 | 61,560 | 3,210 | 64,770 | 800 | 1,750 | 20,240 |
| 80 | 98,500 | 3,950 | 102,450 | 1,500 | 3,200 | 36,570 |
| 140 | 174,420 | 6,920 | 181,340 | 1,800 | 3,600 | 43,240 |
| 225 | 184,680 | 11,060 | 195,740 | 2,000 | 3,600 | 43,870 |
| 280 | 277,020 | 13,830 | 290,850 | 2,400 | 3,600 | 47,130 |
| 560 | 410,400 | 27,660 | 438,060 | 3,000 | 5,400 | 70,140 |

Filtration Rate = 5 gpm/ft

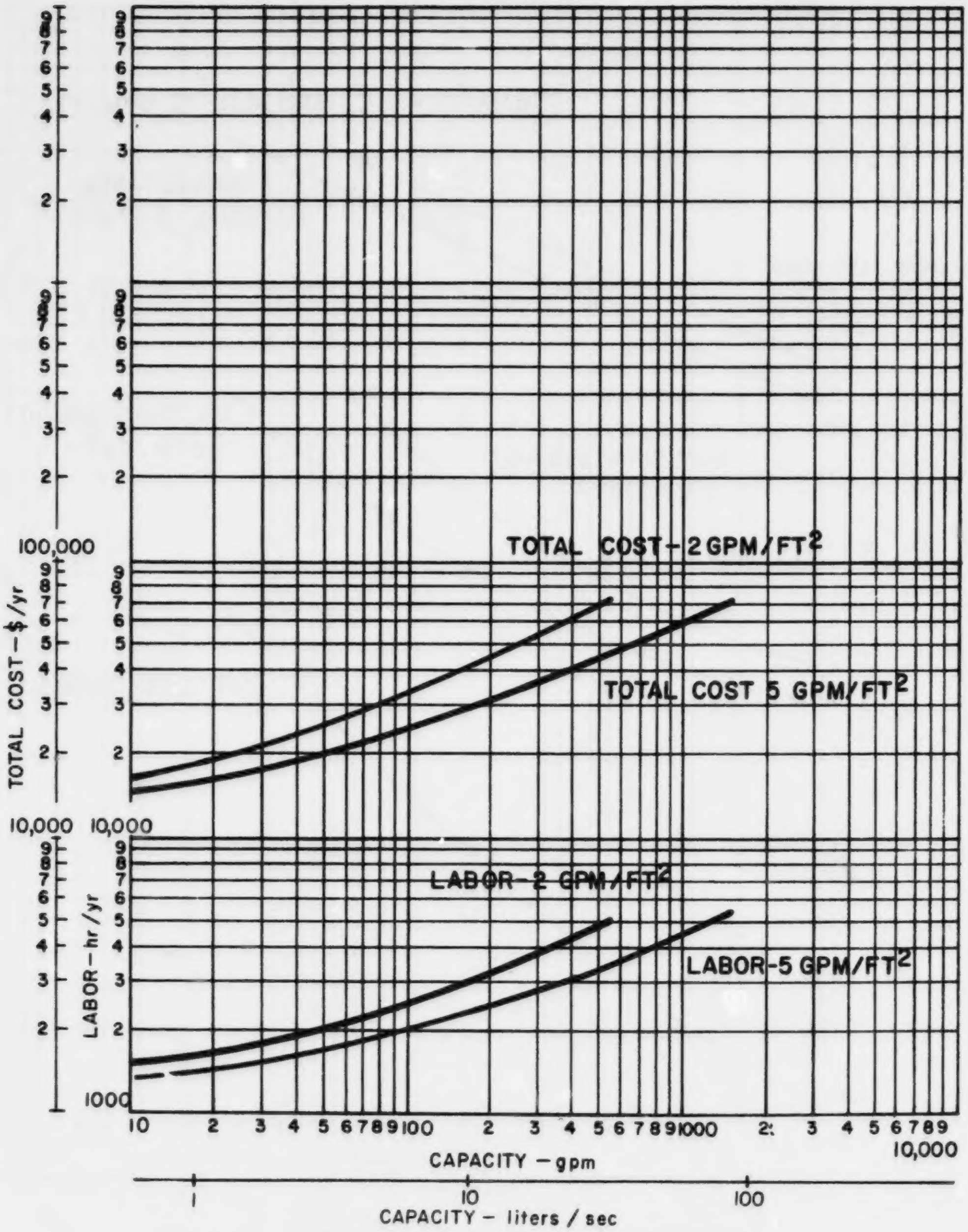
| Plant Capacity - gpm | Energy kw-hr/yr Building | Energy kw-hr/yr Process | Energy kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 10 | 30,780 | 780 | 31,560 | 300 | 1,460 | 15,840 |
| 20 | 38,480 | 1,560 | 40,040 | 550 | 1,460 | 16,350 |
| 100 | 61,560 | 7,810 | 69,370 | 800 | 1,750 | 20,380 |
| 200 | 98,500 | 9,470 | 107,970 | 1,500 | 3,200 | 36,740 |
| 350 | 174,420 | 16,580 | 191,000 | 1,800 | 3,600 | 43,530 |
| 560 | 184,680 | 26,520 | 201,260 | 2,000 | 3,600 | 44,040 |
| 700 | 277,020 | 33,150 | 310,170 | 2,400 | 3,600 | 47,710 |
| 1,400 | 410,400 | 66,300 | 476,700 | 3,000 | 5,400 | 71,300 |

Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
PACKAGE COMPLETE TREATMENT PLANTS

FIGURE 8



OPERATION AND MAINTENANCE
PACKAGE COMPLETE TREATMENT PLANTS

FIGURE 9

## CONSTRUCTION COST

### Conversion of Sand Filter to Carbon Contactor

Existing rapid sand or dual media filters can be converted to carbon contactors by removing filter media and replacing it with granular activated carbon. Filter box dimensions will generally permit installation of a 30-36 inch deep carbon bed which will provide 9-11 minutes of empty bed contact time at 2 gpm/ft$^2$. The existing underdrain and support gravel design can be retained unmodified. The only required modifications are installation of spent carbon collector and transport system and a similar system for return of reactivated carbon to the contactors. Continued operation at the original design filtration rate of 2 gpm/ft$^2$ will require no modification of existing filter rate controls or instrumentation. The backwash rate will be reduced from 15 gpm/ft$^2$ to 10 gpm/ft$^2$ for activated carbon.

Cost curves were developed for modifying existing filters with total bed areas ranging from 350 to 70,000 square feet. The costs include those related to removing and disposing of existing sand (or coal-sand) and gravel, installing carbon collection troughs and related piping and valving outside of filter, installing slurry pumps and related controls for transport and spent carbon to dewatering and regenerating facilities, reactivated carbon storage tank, reactivated carbon return eductors and distribution piping systems to contactors. Carbon transport piping was sized on the basis of 3 pounds of carbon per gallon of water. The costs also include a 30 inch deep bed of granular carbon placed over a 12-inch deep graded gravel underdrain.

The costs for accomplishing these modifications are presented in Table 15 and in Figure 10.

## OPERATION AND MAINTENANCE COST

### Conversion of Sand Filter to Carbon Contactor

Following conversion, operation and maintenance costs should be virtually the same as prior to conversion. Experience at the existing plant, prior to conversion, is therefore the best guide to operation and maintenance costs.

## Table 15

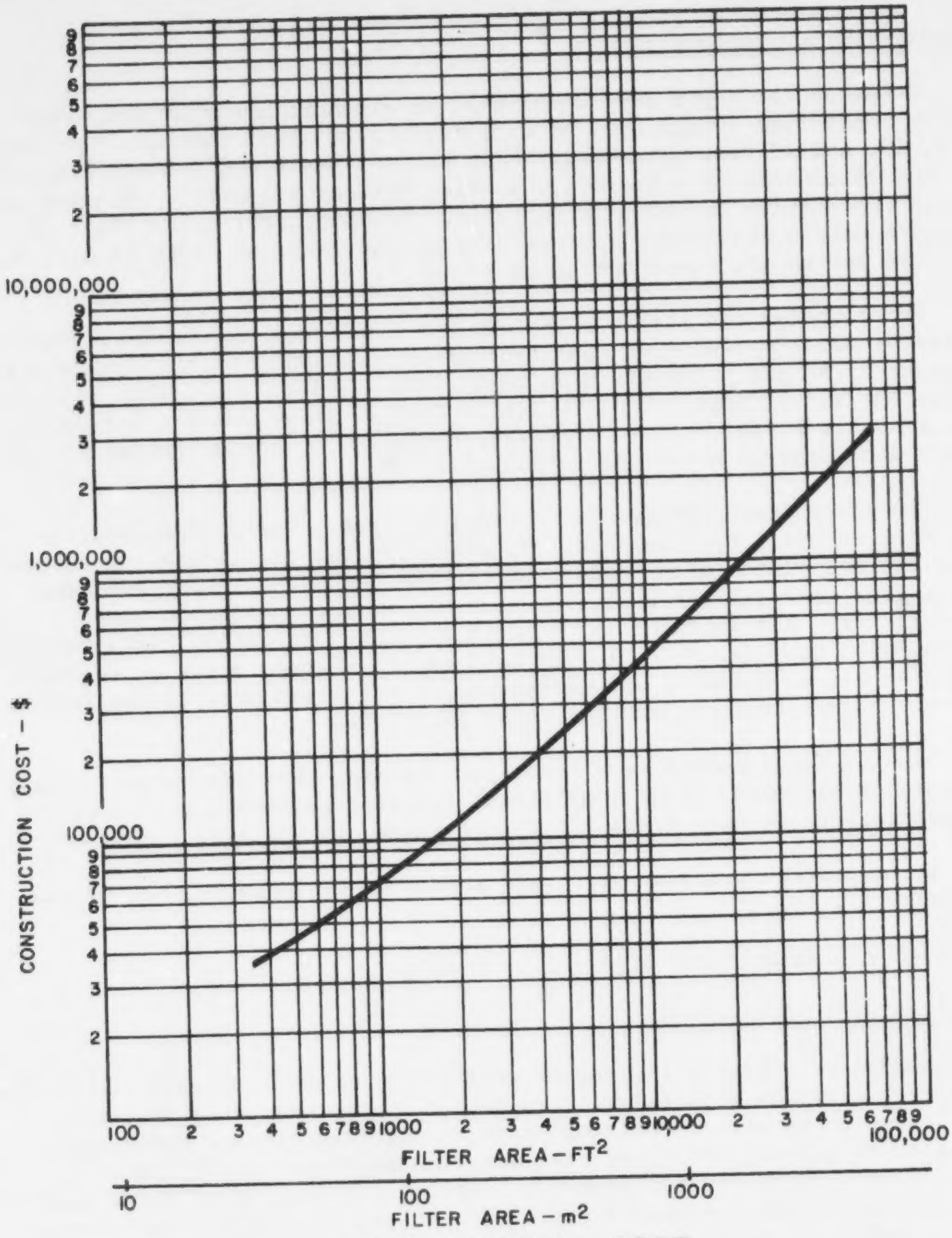
## Construction Cost

## Conversion of Sand Filter to Carbon Contactor

| | | | | | | |
|---|---|---|---|---|---|---|
| [1]Contactor Area, $ft^2$ | 350 | 1,750 | 3,500 | 17,500 | 35,000 | 70,000 |
| [2]Contactor Volume, $ft^3$ | 875 | 4,375 | 8,750 | 43,750 | 87,500 | 175,000 |
| Labor | 8,200 | 26,900 | 45,700 | 166,400 | 322,500 | 615,000 |
| Manufactured Equipment | 11,000 | 21,000 | 22,500 | 80,500 | 142,000 | 278,000 |
| Piping and Valves | 9,850 | 49,150 | 79,750 | 417,500 | 840,500 | 1,547,000 |
| Electrical and Instrumentation | 1,650 | 3,150 | 3,380 | 12,000 | 21,300 | 42,000 |
| SUBTOTAL | 30,700 | 100,200 | 151,330 | 676,400 | 1,326,300 | 2,482,000 |
| Miscellaneous and Contingency | 4,600 | 15,030 | 22,700 | 101,460 | 198,950 | 372,300 |
| TOTAL COST | 35,300 | 115,230 | 174,030 | 777,860 | 1,525,250 | 2,854,300 |

[1] Area of existing filters

[2] Assumes bed depth of 30"



CONSTRUCTION COST
CONVERSION OF SAND FILTER
TO CARBON CONTACTOR

FIGURE 10

## CONSTRUCTION COST

### Pressure Carbon Contactors

Construction costs were developed for pressure granular activated carbon contactors constructed of shop fabricated steel tankage. Bed depths of 5, 10, and 20 feet were used, which provide empty bed contact times of 7.5, 15, and 30 minutes at a hydraulic loading rate of 5 gpm/ft$^2$. Conceptual design information is shown in Table 16. The practical upper limit for pressure carbon contactors is generally in the range of 20 to 25 mgd, but the cost curves are presented up to 50 mgd.

The cost for the steel contactors was based upon pressurized downflow operation using cylindrical ASME code pressure vessels with a design working pressure of 50 psi. Vessels used were either 10 foot or 12 foot diameter by 14, 23, and 33 feet overall height. Carbon contactors are furnished with a nozzle style underdrain and are designed for rapid removal of spent carbon and recharge of virgin carbon.

The costs presented are for a complete carbon contacting facility including vessels, cylinder operated butterfly valves, liquid and carbon handling face piping with headers within the carbon contactor building, flow measurement and other instrumentation, master operations control panel and building. Not included in the cost estimate are carbon contactor supply and backwash pumping, initial activated carbon charge, spent or regenerated activated carbon handling and carbon regeneration and preparation facilities. Separate curves are provided for these facilities

Housing requirements were developed assuming that the carbon columns are totally enclosed. Additional space for pipe galleries and operating and maintenance service areas are also included in the area requirements.

Estimated construction costs are presented in Table 17, 18, 19 and in Figure 11.

## OPERATION AND MAINTENANCE COST

### Pressure Carbon Contactors

Electrical energy requirements were computed assuming that the carbon contactors serve as both filters and carbon contactors; thus periodic backwashing is required. Backwash pumping requirements are based upon one backwash per day for 10 minutes duration at a rate of 12 gpm/ft$^2$. Energy requirements are for backwash pumping, for pumping of spent carbon to regeneration facilities and for return of regenerated carbon. Carbon was assumed to be removed and replaced every two months. Energy for supply pumping to contactors is not included. Building energy requirements are for heating, lighting, ventilating, instrumentation and other general building purposes. It was assumed that the contactors were completely housed.

## Table 16

## Conceptual Designs

## Pressure Carbon Contactors

| Plant Flow mgd | Number of Contactors | Diameter Contactors, ft | Total Contactor[1] Area, ft$^2$ | Total Carbon Volume[3] Ft$^3$ @ Detention Times | | | Plant Area[4] Requirements, ft$^2$ |
|---|---|---|---|---|---|---|---|
| | | | | 7.5 min | 15 min | 30 min | |
| 1 | 2 | 10 | 157 | 680 | 1,570 | 3,140 | 1,750 |
| 10 | 12 | 12[2] | 1,357 | 6,790 | 13,570 | 27,140 | 4,800 |
| 50 | 60 | 12 | 6,786 | 33,930 | 67,860 | 135,720 | 21,000 |

[1] Carbon contactors sized for 5 gpm/ft$^2$ application rate

[2] Maximum sized contactor for shop fabrication and over-the-road shipment

[3] Volumes determined at bed depth of 5, 10 and 20 feet

[4] Assumes carbon contactors are totally enclosed

### Table 17

### Construction Cost

### Pressure Carbon Contactors

### (7.5 min empty bed contact time - 5 ft bed depth)

| | | | |
|---|---|---|---|
| Contactor Volume - $ft^3$ | 680 | 6,790 | 33,930 |
| Contactor Area - $ft^2$ | 157 | 1,357 | 6.786 |
| Excavation and Sitework | 500 | 1,330 | 5,880 |
| Manufactured Equipment | 46,200 | 385,800 | 1,832,600 |
| Concrete | 2,070 | 5,330 | 23,330 |
| Steel | 1,020 | 2,560 | 11,200 |
| Labor | 17,500 | 99,430 | 446,000 |
| Pipe and Valves | 14,350 | 127,300 | 639,620 |
| Electrical and Instrumentation | 14,930 | 79,200 | 410,420 |
| Housing | 61,250 | 158,400 | 630,000 |
| SUBTOTAL | 157,820 | 859,350 | 3,999,050 |
| Miscellaneous and Contingency | 23,670 | 128,900 | 599,860 |
| TOTAL | 181,490 | 988,250 | 4,598,910 |

## Table 18

### Construction Cost

### Pressure Carbon Contactors

(15 min. empty bed contact time - 10 ft bed depth)

| | | | |
|---|---|---|---|
| Contactor Volume - $ft^3$ | 1,570 | 13,570 | 67,860 |
| Contactor Area - $ft^2$ | 157 | 1,357 | 6,786 |
| Excavation & sitework | 500 | 1,330 | 5,880 |
| Manufactured Equipment | 52,280 | 426,740 | 2,037,320 |
| Concrete | 2,070 | 5,330 | 23,330 |
| Steel | 1,020 | 2,560 | 11,200 |
| Labor | 18,500 | 105,430 | 476,000 |
| Pipe and Valves | 15,790 | 138,760 | 685,390 |
| Electrical and Instrumentation | 14,980 | 79,200 | 410,420 |
| Housing | 78,750 | 206,400 | 861,000 |
| SUBTOTAL | 183,890 | 965,750 | 4,510,540 |
| Miscellaneous and Contingency | 27,580 | 144,860 | 676,580 |
| TOTAL | 211,470 | 1,110,610 | 5,187,120 |

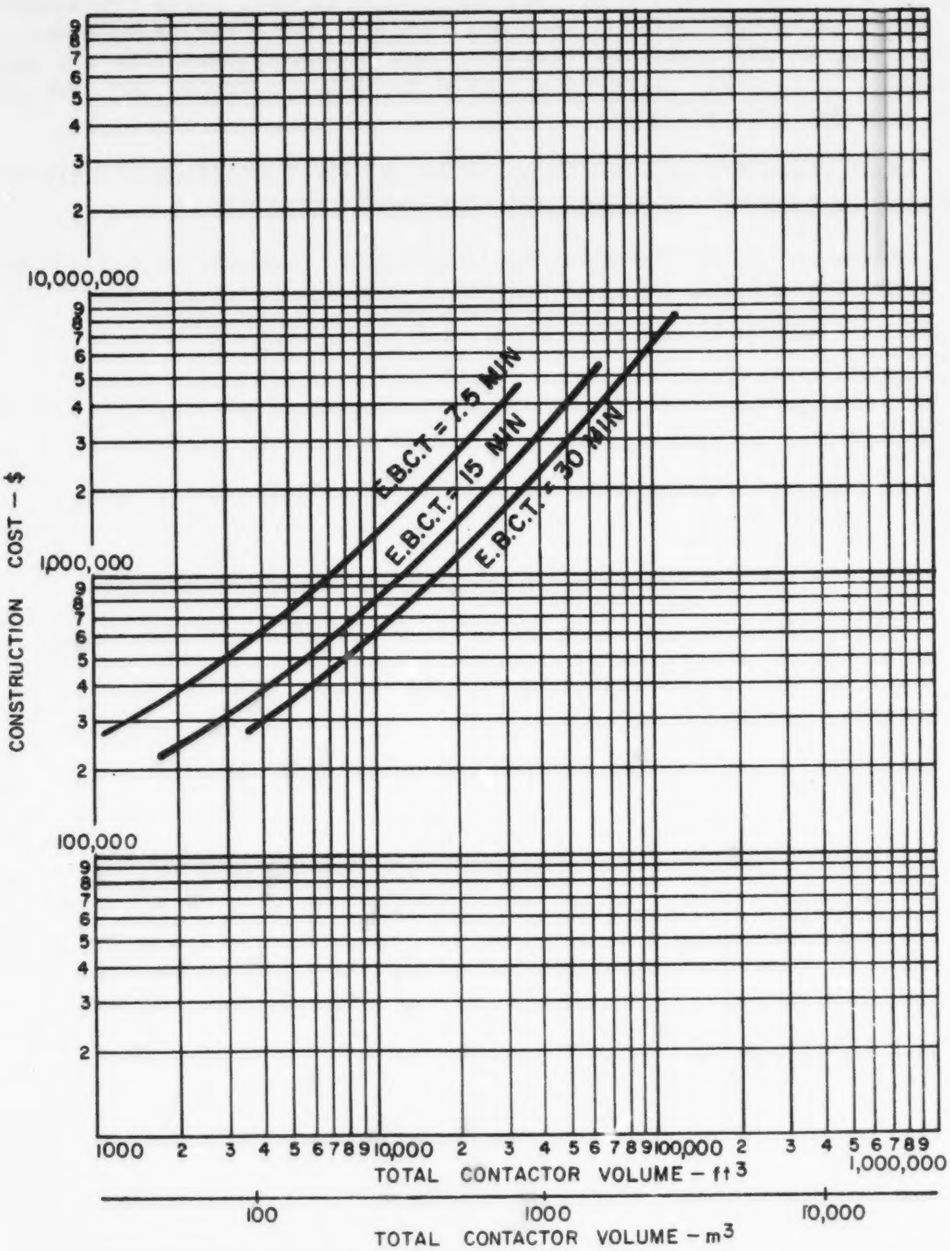
## Table 19

### Construction Cost

### Pressure Carbon Contactors

### (30 min. empty bed contact time - 20 ft bed depth)

| | | | |
|---|---|---|---|
| Contactor Volume - $ft^3$ | 3,140 | 27,140 | 135,720 |
| Carbon Area - $ft^2$ | 157 | 1,357 | 6,786 |
| Excavation and Site Work | 500 | 1,330 | 5,880 |
| Manufactured Equipment | 72,860 | 706,540 | 3,356,050 |
| Concrete | 2,480 | 6,400 | 28,000 |
| Steel | 1,120 | 2,820 | 12,320 |
| Labor | 21,280 | 121,250 | 547,400 |
| Pipe and Valves | 17,400 | 208,600 | 1,054,000 |
| Electrical and Instrumentation | 15,680 | 83,200 | 431,000 |
| Housing | 148,750 | 384,000 | 1,638,000 |
| SUBTOTAL | 280,070 | 1,514,140 | 7,072,650 |
| Miscellaneous and Contingency | 42,010 | 227,120 | 1,060,950 |
| TOTAL | 322,080 | 1,741,260 | 8,133,550 |



CONSTRUCTION COST
PRESSURE CARBON CONTACTORS

FIGURE 11

Maintenance material costs reflect estimated annual requirements for general supplies, pump seals, instrumentation repair, valve replacement or repair and other miscellaneous work items. Costs for replacement of carbon lost during contactor operation and carbon regeneration are not included. A separate curve is provided for makeup carbon, and this cost must be added separately.

Labor costs are related to operation of the facility and include those required to maintain equipment and supervise operation.

Operation and maintenance requirements for pressure carbon contactors are summarized in Table 20 and Figures 12 and 13.

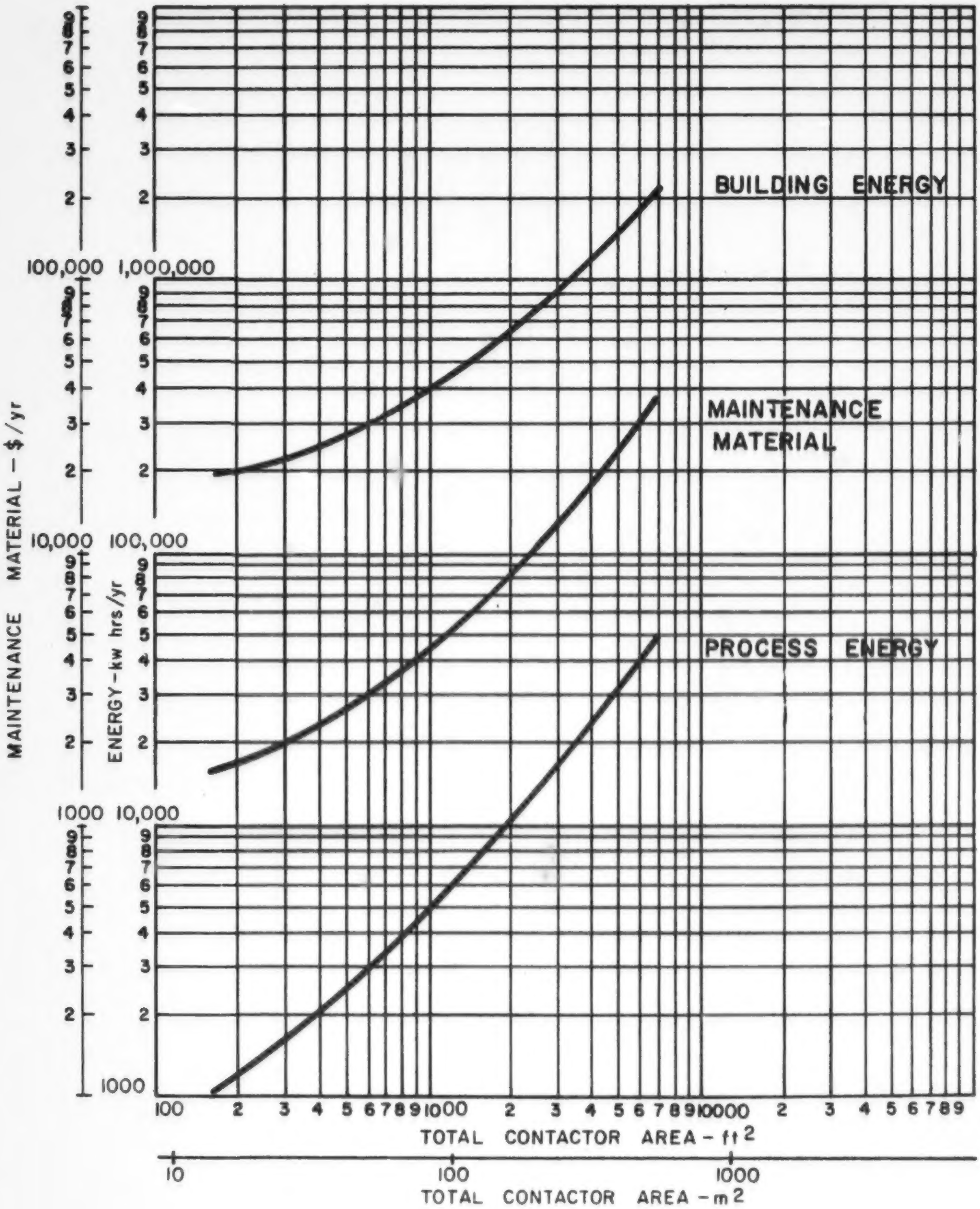
## Table 20

## Operation and Maintenance Summary

## Pressure Carbon Contactors

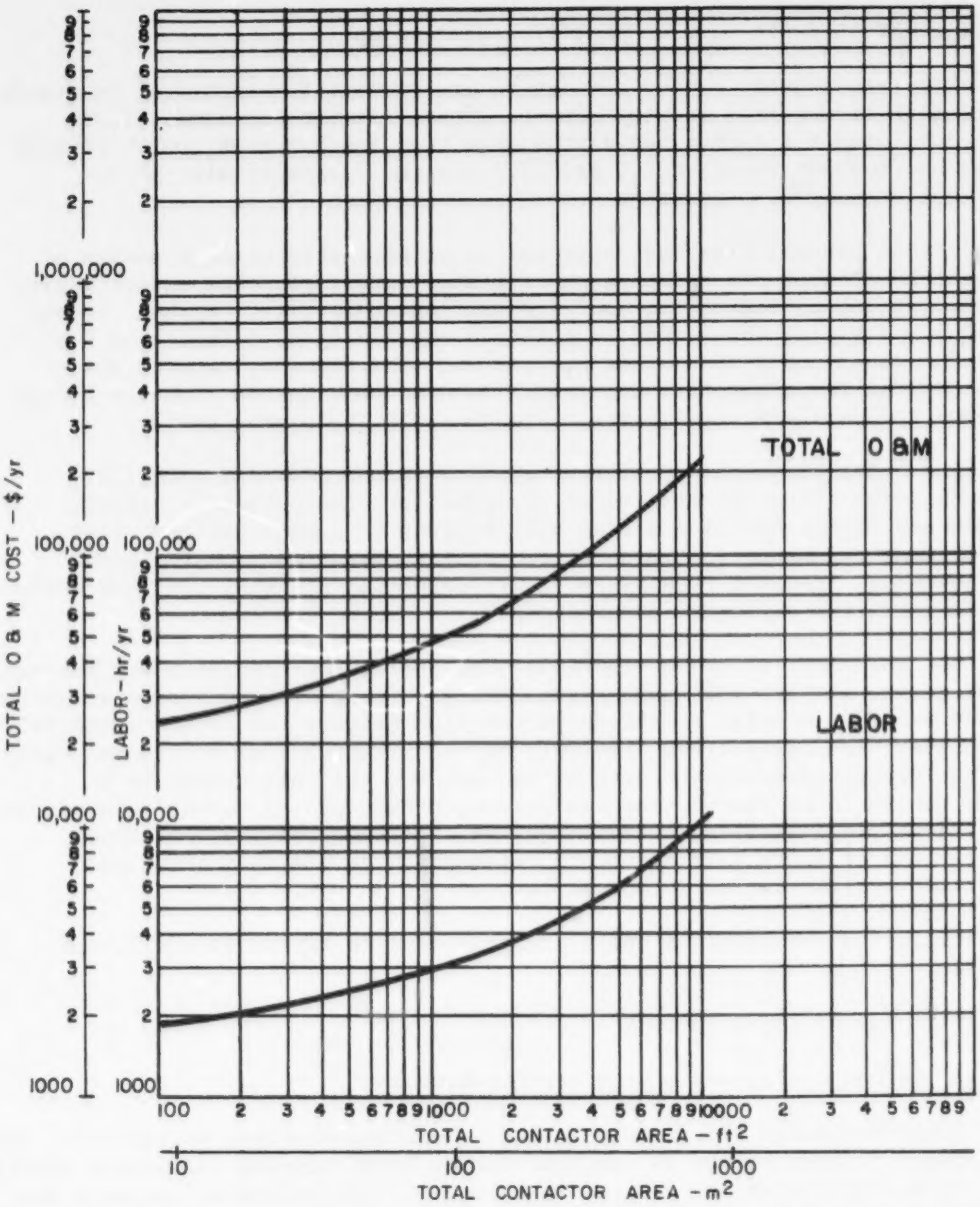
| Total Surface Area-ft$^2$ | Energy - kw-hr/yr |  |  | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
|  | Process | Building | Total |  |  |  |
| 157 | 916 | 179,550 | 180,470 | 1,500 | 2,000 | 26,910 |
| 1,357 | 7,967 | 492,480 | 500,450 | 7,500 | 3,500 | 57,510 |
| 6,786 | 39,746 | 2,154,600 | 2,194,350 | 35,000 | 7,500 | 175,830 |

*Calculated using $0.03/kw-hr and $10.00/hour of labor



OPERATION AND MAINTENANCE
PRESSURE CARBON CONTACTORS

FIGURE 12



OPERATION AND MAINTENANCE
PRESSURE CARBON CONTACTORS

FIGURE 13

## CONSTRUCTION COST

### Gravity Carbon Contactors - Concrete Construction

Concrete gravity carbon contactors are essentially identical to gravity filtration structures, and the same conceptual layout was used. Costs were developed for carbon bed depths of 5 feet and 8.3 feet, which provide empty bed contact times of 7.5 and 12.5 minutes, respectively, at an application rate of 5 gpm/ft$^2$.

Carbon removal from the contactor is accomplished using a series of troughs located at the carbon/support gravel interface. The carbon slurry is then pumped to dewatering and regeneration facilities. Carbon removal troughs and piping were sized to maintain a velocity of 3 ft/second with a carbon slurry of 3 lbs carbon per gallon. The troughs, each of which have plug style valves, are manifolded into a spent carbon transfer system. Regenerated carbon is transported through a similar piping system.

The costs presented are for a complete carbon contacting facility including the contactor structure, cylinder operated butterfly valves, liquid and carbon handling piping with headers in a pipe gallery, flow measurement and other instrumentation, master operations control panel and building. Housing requirements were developed assuming that the entire carbon contactor structure is enclosed.

Not included in the cost estimate for the carbon contactor are backwash pumping, the initial activated carbon charge, spent or regenerated activated carbon handling outside of the contactor pipe gallery and carbon regeneration and preparation facilities. Separate curves are presented for these costs. In developing construction costs it was assumed that all carbon in a contactor would be removed and replaced with regenerated carbon in a single operation. This handling method requires that regeneration facilities be designed to store both spent and regenerated carbon in quantities equivalent to the amount in one contactor.

Estimated construction costs are presented in Tables 21 and 22 and in Figure 14.

## OPERATION AND MAINTENANCE COST

### Gravity Carbon Contactors - Concrete Construction

Building energy requirements are for building heating, ventilation, and lighting. Process energy is required for backwash pumping and carbon slurry pumping during carbon removal and replacement. The backwash frequency was assumed to be once per day, for 10 minutes at 12 gpm/ft$^2$. For carbon removal, a regeneration frequency of every two months, and a slurry concentration of 3 pounds of carbon per gallon of water were utilized. Process energy requirements are virtually identical for the two different carbon bed depths.

## Table 21

### Construction Cost

### Gravity Carbon Contactors - Concrete Construction

### (7.5 min. empty bed contact time - 5 foot bed depth)

| Total Contactor Volume - $ft^3$ | 700 | 3,500 | 7,000 | 35,000 | 70,000 | 140,000 |
|---|---|---|---|---|---|---|
| Total Contactor Area - $ft^2$ | 140 | 700 | 1,400 | 7,000 | 14,000 | 28,000 |
| Excavation and Sitework | 1,580 | 2,900 | 4,430 | 13,010 | 20,550 | 34,850 |
| Manufactured Equipment | 25,770 | 50,800 | 67,450 | 240,800 | 410,780 | 760,800 |
| Concrete | 6,210 | 15,730 | 22,030 | 82,880 | 134,360 | 239,190 |
| Steel | 4,790 | 9,000 | 12,810 | 61,300 | 102,670 | 175,030 |
| Labor | 19,560 | 52,160 | 95,980 | 311,940 | 445,510 | 875,890 |
| Pipe and Valves | 31,580 | 102,260 | 193,920 | 562,000 | 812,800 | 1,376,500 |
| Electrical and Instrumentation | 6,350 | 10,400 | 10,510 | 42,440 | 58,800 | 92,730 |
| Housing | 16,250 | 37,800 | 65,910 | 272,600 | 480,250 | 904,350 |
| SUBTOTAL | 112,090 | 280,330 | 473,040 | 1,586,370 | 2,465,720 | 4,459,340 |
| Miscellaneous and Contingency | 16,810 | 42,050 | 70,960 | 237,960 | 369,860 | 668,900 |
| TOTAL | 128,900 | 322,380 | 544,000 | 1,824,330 | 2,835,580 | 5,128,240 |

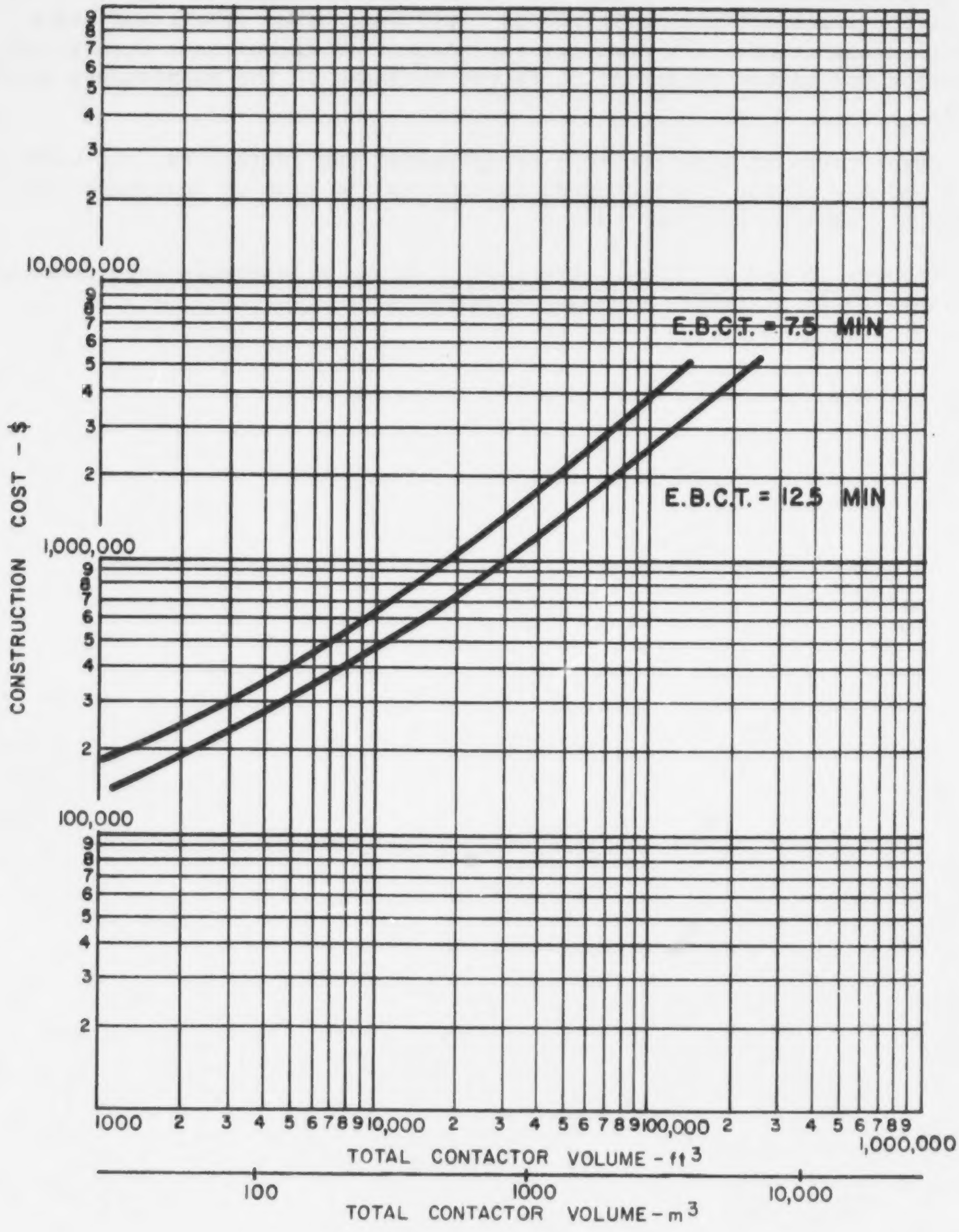
## Table 22

### Construction Cost

### Gravity Carbon Contactors - Concrete Construction

(12.5 min. empty bed contact time - 8.2 foot bed depth)

| Total Contactor Volume - $ft^3$ | 700 | 3,500 | 7,000 | 35,000 | 70,000 | 140,000 |
|---|---|---|---|---|---|---|
| Total Contactor Area - $ft^2$ | 140 | 700 | 1,400 | 7,000 | 14,000 | 28,000 |
| Excavation and Sitework | 2,110 | 3,880 | 5,910 | 17,350 | 27,400 | 46,400 |
| Manufactured Equipment | 25,770 | 50,080 | 67,450 | 240,800 | 410,780 | 760,800 |
| Concrete | 7,560 | 19,150 | 29,420 | 104,810 | 170,300 | 291,190 |
| Steel | 5,840 | 10,140 | 17,940 | 74,630 | 124,990 | 213,080 |
| Labor | 23,810 | 63,540 | 116,850 | 379,760 | 542,360 | 1,103,630 |
| Pipe and Valves | 31,580 | 102,260 | 193,920 | 562,000 | 812,800 | 1,376,500 |
| Electrical and Instrumentation | 6,350 | 10,400 | 10,510 | 42,440 | 58,800 | 92,730 |
| Housing | 16,250 | 37,800 | 65,910 | 272,600 | 480,250 | 904,350 |
| SUBTOTAL | 119,270 | 297,250 | 507,910 | 1,694,120 | 2,627,680 | 4,788,680 |
| Miscellaneous and Contingency | 17,890 | 44,590 | 76,190 | 254,120 | 394,150 | 718,300 |
| TOTAL | 137,160 | 341,840 | 584,100 | 1,948,240 | 3,021,830 | 5,506,980 |



CONSTRUCTION COST
GRAVITY CARBON CONTACTORS
CONCRETE CONSTRUCTION

FIGURE 14

Maintenance material costs include the cost of general supplies, backwash and carbon transport pump maintenance, instrumentation repair and other miscellaneous items. The cost for replacement of carbon lost during contactor operation and carbon regeneration is not included in the maintenance material costs.

Labor costs include the cost of operating the contactors, the backwash pumps and the carbon slurry pumps, as well as the cost of instrument and equipment repairs, and supervision.

Figures 15 and 16 present the operation and maintenance requirements, and Table 23 is a summary of these requirements.

## Table 23

## Operation and Maintenance Summary

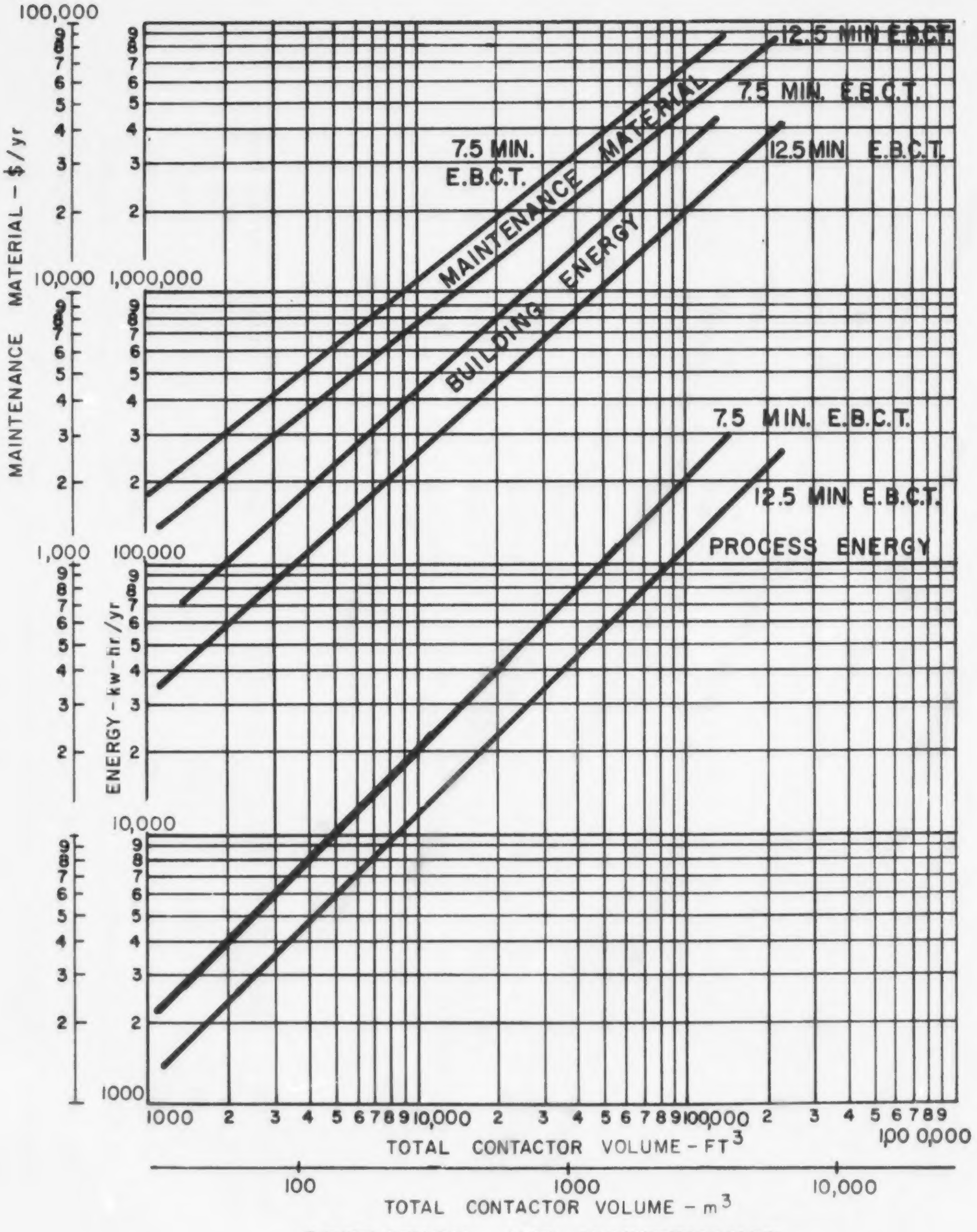
## Gravity Carbon Contactors - Concrete Construction

7.5 minute empty bed contact time - 5 foot bed depth

| Total Contactor Volume - $ft^3$ | Electrical Energy - kw-hr/yr | | | Maintenance Material $/yr | Labor hr/yr | Total O&M Costs - $ |
|---|---|---|---|---|---|---|
| | Building | Process | Total | | | |
| 700 | 44,120 | 1,370 | 45,490 | 1,400 | 1,850 | 21,260 |
| 3,500 | 151,850 | 6,820 | 158,670 | 4,800 | 2,220 | 31,760 |
| 7,000 | 279,070 | 13,630 | 292,700 | 8,500 | 2,600 | 43,280 |
| 35,000 | 1,190,160 | 68,150 | 1,258,310 | 31,000 | 6,670 | 135,450 |
| 70,000 | 2,165,890 | 136,300 | 2,302,190 | 50,600 | 13,150 | 251,170 |
| 140,000 | 4,123,490 | 273,070 | 4,396,560 | 90,000 | 25,700 | 478,900 |

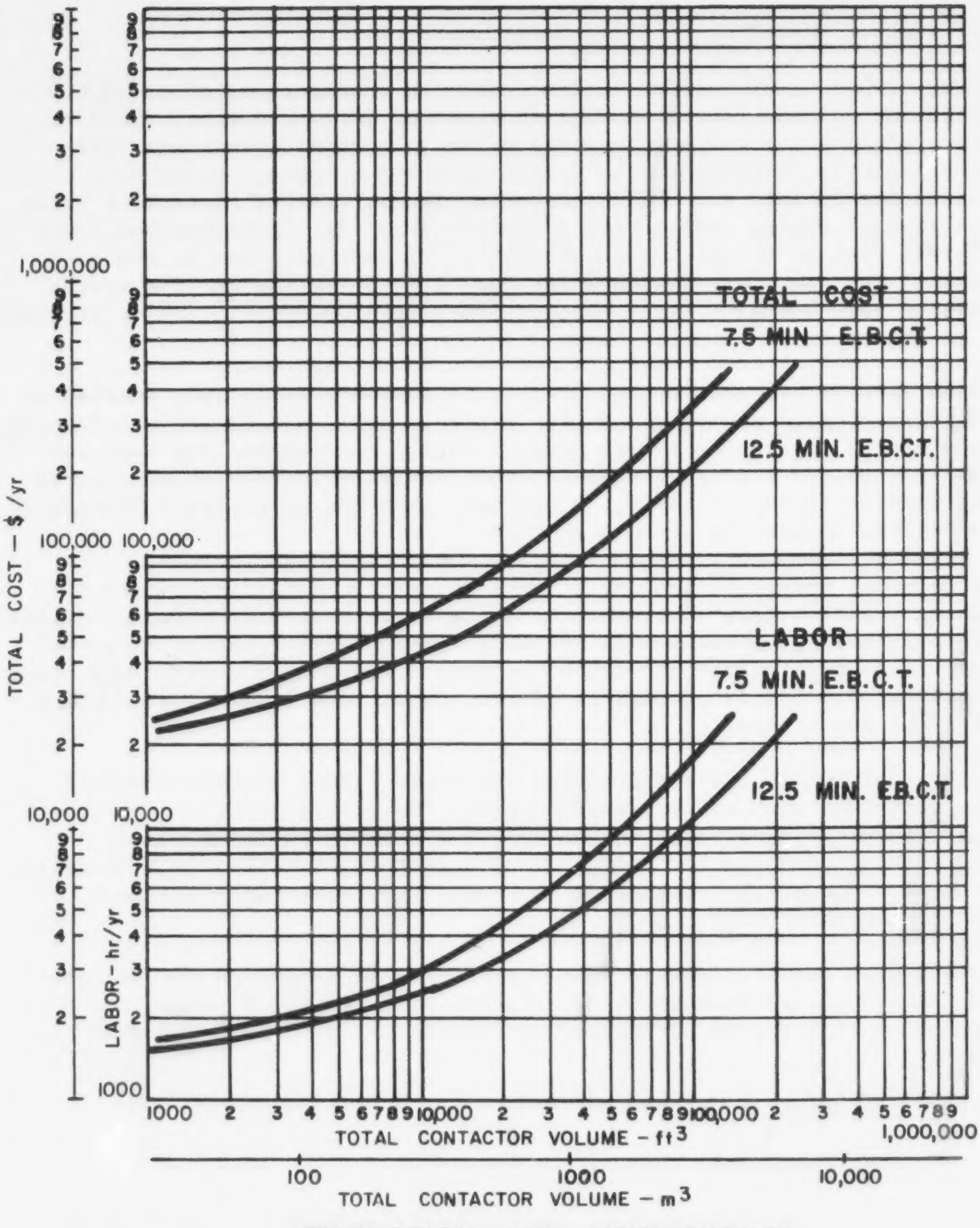
12.5 minute empty bed contact time - 8.3 foot bed depth

| Total Contactor Volume - $ft^3$ | Electrical Energy - kw-hr/yr | | | Maintenance Material $/yr | Labor hr/yr | Total O&M Costs - $ |
|---|---|---|---|---|---|---|
| | Building | Process | Total | | | |
| 1,160 | 44,120 | 1,380 | 45,500 | 1,400 | 1,850 | 21,270 |
| 5,810 | 151,850 | 6,900 | 158,750 | 4,800 | 2,220 | 31,760 |
| 11,620 | 279,070 | 13,790 | 292,860 | 8,500 | 2,600 | 43,290 |
| 58,100 | 1,190,160 | 68,790 | 1,259,130 | 31,000 | 6,670 | 135,470 |
| 116,200 | 2,165,890 | 137,940 | 2,303,830 | 50,600 | 13,150 | 251,210 |
| 232,400 | 4,123,490 | 276,350 | 4,399,840 | 90,000 | 25,700 | 479,000 |



OPERATION AND MAINTENANCE
GRAVITY CARBON CONTACTORS-
CONCRETE CONSTRUCTION

FIGURE 15



**OPERATION AND MAINTENANCE GRAVITY CARBON CONTACTORS — CONCRETE CONSTRUCTION**

**FIGURE 16**

## CONSTRUCTION COST

### Gravity Carbon Contactors - Steel Construction

For carbon treatment facilities requiring in excess of about 30,000 cubic feet of carbon contact volume, the use of large diameter, field erected, steel gravity contactors may offer an economic advantage over smaller diameter, factory-built, pressure carbon columns. Costs were developed for 20 foot and 30 foot diameter steel, gravity contactors using the conceptual design information listed in Table 24. A carbon bed depth of 20 feet with an overall vessel height of 35 feet was used in the cost analysis. The units are designed for down flow operation and the system hydraulics were sized using an application rate of 5 gpm/ft$^2$, which provides a 30 minute empty bed contact time.

The vessels are constructed of factory formed steel plates erected at the jobsite. Units are provided with a nozzle style underdrain eliminating the need for a supporting gravel layer. Carbon is removed from each contactor as required for regeneration through multiple carbon drawoff pipes in the underdrain support plate. Regenerated carbon is returned through a piping system to the top of each contactor.

The costs presented are for a complete carbon contacting facility including vessels, face and interconnecting piping, access walkways, cylinder operated butterfly valves on all hydraulic piping with manually operated ball or knife type valves on carbon handling system, flow control and other instrumentation, master operations control panel, and a building completely housing the contactors.

Not included in the construction costs are carbon contactor supply pumping, surface wash and backwash pumping, the initial activated carbon charge, spent or regenerated carbon handling facilities (exclusive of piping within the contactor building) or carbon regeneration or preparation facilities. Curves for estimating the costs for these facilities are presented separately.

Estimated construction costs are presented in Tables 25 and 26 for 20-foot and 30-foot diameter units respectively. Figure 17 shows the construction cost curves for systems using the two different diameter contactors.

## OPERATION AND MAINTENANCE COST

### Gravity Carbon Contactors - Steel Construction

Building energy requirements are for building heating, ventilation, and lighting. Process energy is required for the backwash pumping and carbon slurry pumping during carbon removal and replacement. The backwash frequency was assumed to be once per day, for 10 minutes at 12 gpm/ft$^2$. For carbon removal, a regeneration frequency of every two months, and a slurry concentration of 3 pounds of carbon per gallon of water were utilized. Process energy requirements are virtually identical for the two different carbon bed depths.

## Table 24

## Conceptual Design

## Gravity Carbon Contactors - Steel Construction

(20 foot carbon bed depth)

| Plant Flow mgd | Total Contactor Bed Area, $Ft^2$ | | Number Contactors | | Total Carbon Volume, $ft^3$ | | Plant Area Requirements, $ft^2$ | |
|---|---|---|---|---|---|---|---|---|
| | 20' diam. | 30' diam. | 20' diam. | 30' diam. | 20' diam. | 30' diam. | 20' diam. | 30' diam. |
| 10 | 1,570 | -- | 5 | -- | 31,400 | -- | 6,500 | -- |
| 50 | 7,850 | 7,065 | 25 | 10 | 157,000 | 141,300 | 33,000 | 26,000 |
| 100 | 15,700 | 14,130 | 50 | 20 | 314,000 | 282,600 | 66,000 | 50,000 |
| 200 | 31,400 | 28,260 | 100 | 40 | 628,000 | 565,200 | 126,000 | 95,000 |

### Table 25

### Construction Cost

### Gravity Carbon Contactors - Steel Construction

### (20' diam. tanks)

| Total Contactor Volume - $ft^3$ | 31,400 | 157,000 | 314,000 | 628,000 |
|---|---|---|---|---|
| Excavation and Sitework | 1,950 | 6,240 | 11,040 | 20,700 |
| Manufactured Equipment | 321,400 | 1,526,800 | 2,989,000 | 5,785,560 |
| Concrete | 7,220 | 25,920 | 44,620 | 86,400 |
| Steel | 3,450 | 12,720 | 22,080 | 41,400 |
| Labor | 63,000 | 299,000 | 556,000 | 1,023,300 |
| Pipe and Valves | 132,400 | 635,500 | 1,352,000 | 2,488,000 |
| Electrical and Instrumentation | 48,200 | 198,500 | 388,600 | 752,000 |
| Housing | 585,000 | 2,706,000 | 5,346,000 | 10,080,000 |
| SUBTOTAL | 1,162,620 | 5,410,680 | 10,709,340 | 20,277,360 |
| Miscellaneous and Contingency | 174,390 | 811,600 | 1,606,400 | 3,041,600 |
| TOTAL | 1,337,010 | 6,222,280 | 12,315,740 | 23,318,960 |

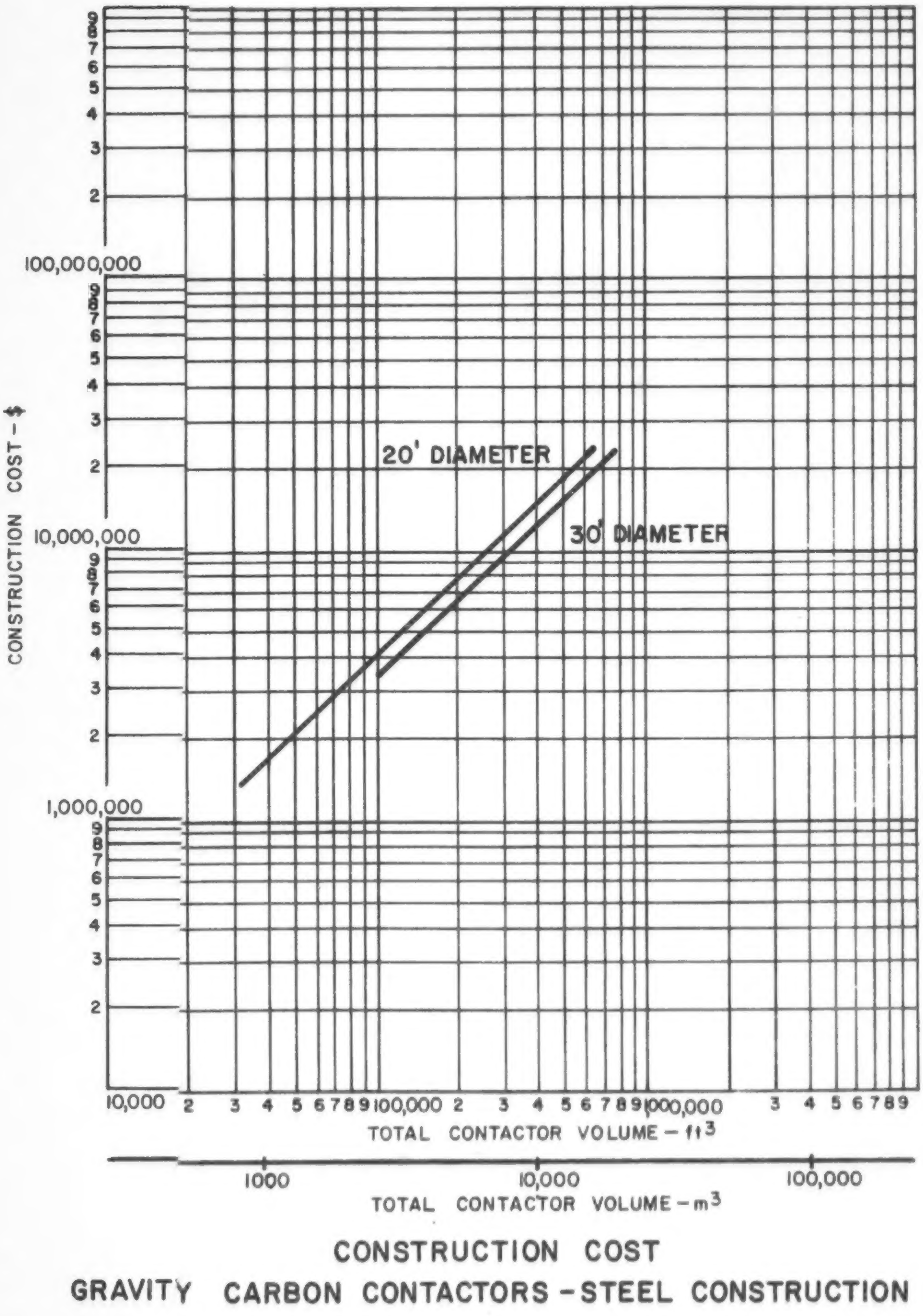
## Table 26

## Construction Cost

## Gravity Carbon Contactors - Steel Construction

## (30' diam. tanks)

| Total Contactor Volume, ft$^3$ | 141,300 | 282,600 | 565,200 |
|---|---|---|---|
| Excavation and Sitework | 6,800 | 12,500 | 23,800 |
| Manufactured Equipment | 1,251,000 | 2,447,000 | 4,845,000 |
| Concrete | 28,000 | 53,000 | 105,000 |
| Steel | 13,800 | 26,000 | 50,000 |
| Labor | 251,000 | 465,000 | 897,000 |
| Pipe and Valves | 532,000 | 1,028,000 | 1,986,000 |
| Electrical and Instrumentation | 163,000 | 318,000 | 630,000 |
| Housing | 2,132,000 | 4,050,000 | 7,695,000 |
| SUBTOTAL | 4,378,000 | 8,400,000 | 16,232,000 |
| Miscellaneous and Contingency | 656,700 | 1,260,000 | 2,434,800 |
| TOTAL | 5,034,700 | 9,660,000 | 18,666,800 |



CONSTRUCTION COST
GRAVITY CARBON CONTACTORS - STEEL CONSTRUCTION

FIGURE 17

Maintenance material costs include the cost of general supplies, backwash and carbon transport pump maintenance, instrumentation repair and other miscellaneous items. The cost for replacement of carbon lost during contactor operation and carbon regeneration is not included in the maintenance material costs. A separate curve is provided for makeup carbon and this cost must be added separately.

Labor costs include the cost of operating the contactors, the backwash pumps, and the carbon slurry pumps, as well as the cost of instrument and equipment repairs, and supervision.

Figures 18 and 19 present the operation and maintenance requirements, and Table 27 is a summary of these requirements.

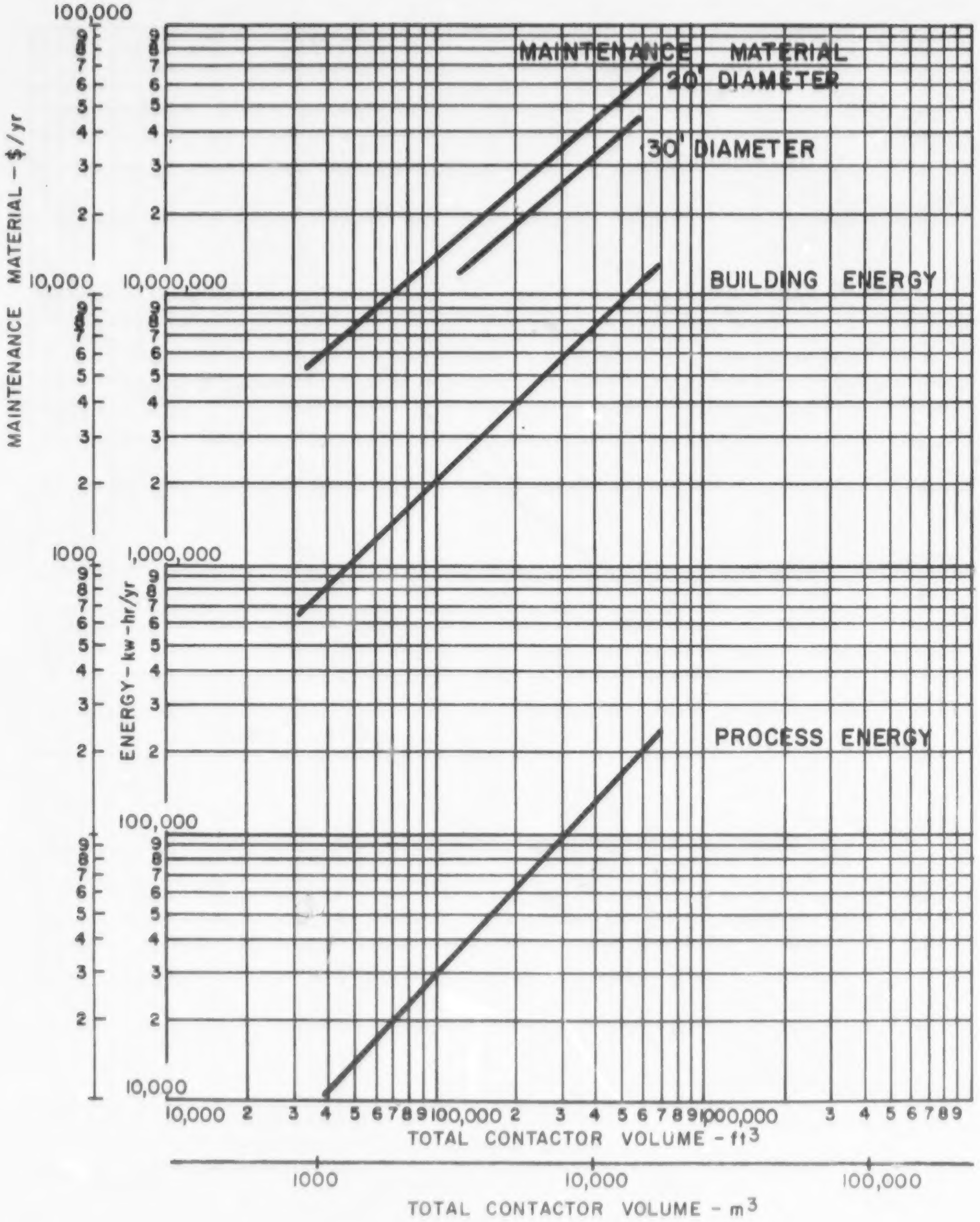
### Table 27

### Operation and Maintenance Summary

### Gravity Carbon Contactors - Steel Construction

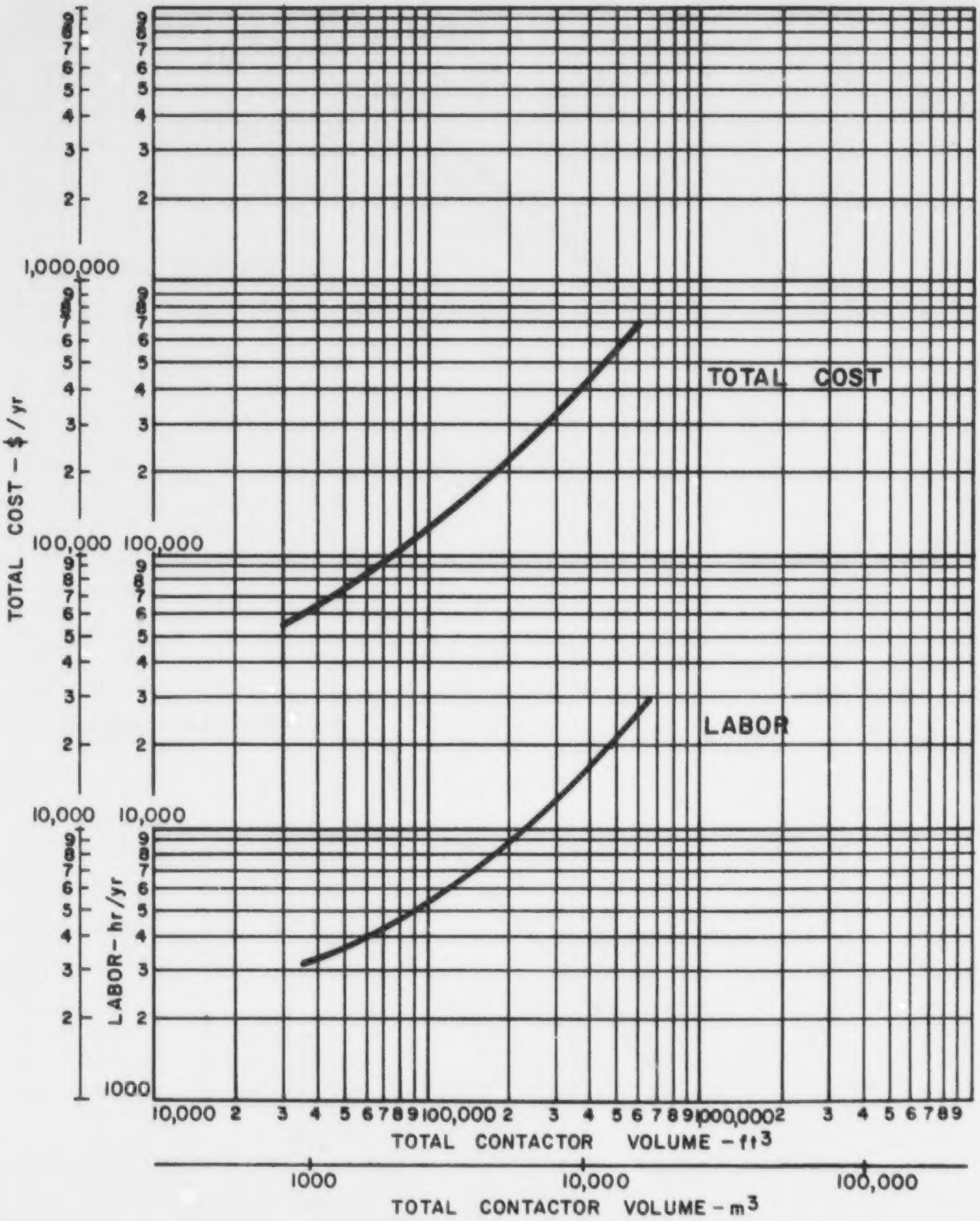
| Contactor Diameter - ft | Carbon Volume - $ft^3$ | Electrical Energy - kw-hr/yr Building | Electrical Energy - kw-hr/yr Process | Electrical Energy - kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|---|
| 20 | 31,400 | 666,900 | 12,030 | 678,930 | 5,000 | 3,000 | 55,370 |
| 20 | 157,100 | 3,385,800 | 60,170 | 3,445,970 | 20,000 | 7,000 | 193,380 |
| 20 | 314,000 | 6,771,600 | 120,340 | 6,891,940 | 35,000 | 14,000 | 381,760 |
| 20 | 628,000 | 12,927,600 | 240,680 | 13,168,280 | 65,000 | 27,000 | 730,050 |
| 30 | 141,300 | 2,668,000 | 54,150 | 2,722,150 | 15,000 | 6,800 | 164,660 |
| 30 | 282,600 | 5,130,000 | 108,300 | 5,238,300 | 25,000 | 13,500 | 317,150 |
| 30 | 565,200 | 9,750,000 | 216,600 | 9,966,600 | 40,000 | 26,000 | 600,000 |

*Calculated using $0.03/kw-hr and $10.00/hour of labor



OPERATION AND MAINTENANCE
GRAVITY CARBON CONTACTORS – STEEL CONSTRUCTION

FIGURE 18



OPERATION AND MAINTENANCE
GRAVITY CARBON CONTACTORS – STEEL CONSTRUCTION

FIGURE 19

## CONSTRUCTION COST

### Off-Site Regional Carbon Regeneration - Handling and Transportation

Construction costs were developed for combination granular activated carbon dewatering/storage bins. These facilities would be required for storage and dewatering of carbon removed from pressure or gravity contactors, prior to transport to off-site regeneration facilities. Such storage provisions are generally provided where spent carbon must be accumulated before it can be economically handled, transported and regenerated at a regional facility.

Two different design configurations were used to develop the cost curves. Storage bins of 2,000 cubic feet and less are elevated, 12 foot diameter, cylindrical tanks with conical bottoms. The 5,000 cubic foot bin is an elevated, three hopper, rectangular tank. For larger storage requirements, multiple units would be used.

Tanks are elevated for gravity loading to dump trucks. The overall height of the storage bins was limited to 30 feet. All designs include stainless steel dewatering screens and associated piping and valving to conduct water to waste drains. Tanks are field fabricated of braced, 1/4 inch, shop formed steel plate protected by a suitable coating system. The tanks are not housed. No costs are included for trucks necessary to haul dewatered carbon to the regional regeneration facility. These costs must be added separately.

Construction costs are summarized in Table 28 and illustrated in Figure 20.

## OPERATION AND MAINTENANCE

### Off-Site Regional Carbon Regeneration - Handling and Transportation

Granular activated carbon may be removed from the contactor, dewatered, and hauled to a regionally located regeneration facility serving a number of treatment plants within a distance of up to 100 miles. Included in the costs are the fuel, labor and maintenance requirements to load spent carbon from dewatered carbon storage tanks to 30 cubic yard, semi-dump trailers, haul to the regeneration facility, unload, reload reactivated carbon from bulk storage, return to the treatment plant, and discharge either to on-site storage tanks or directly to the carbon contactors. For all travel distances it was assumed that the entire operation would be accomplished in an 8-hour day.

The annual fuel requirements are based upon a diesel fuel consumption of 3.5 mpg.

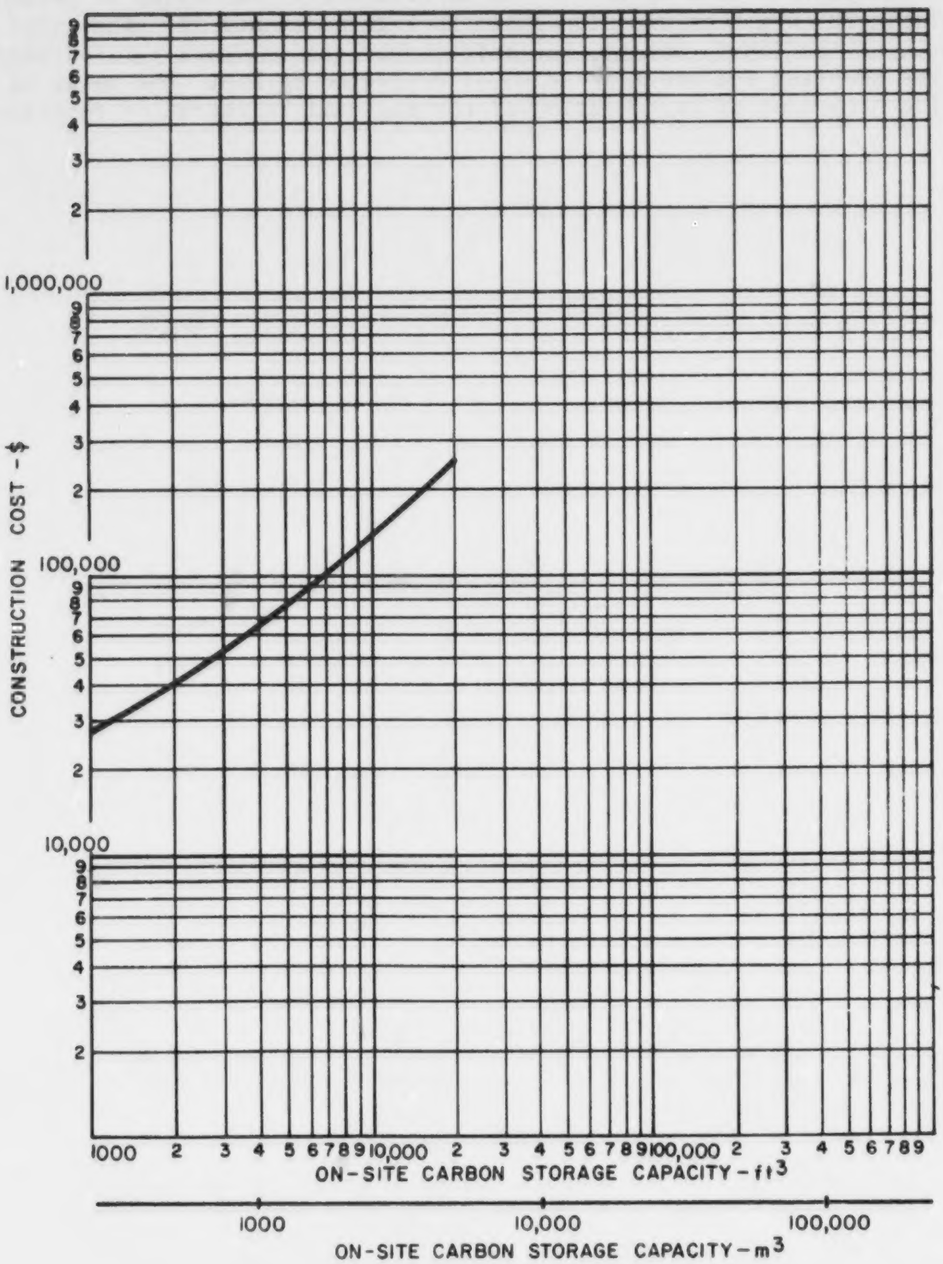
Maintenance materials are only for the trucks, and were computed assuming a unit cost of $0.30 per mile.

## Table 28

## Construction Cost

## Off-Site Regional Carbon Regeneration - Handling and Transportation

| On Site Carbon Storage Capacity - $Ft^3$ | 1,000 | 5,000 | 20,000 |
|---|---|---|---|
| Excavation and Sitework | 200 | 350 | 1,400 |
| Manufactured Equipment | 18,150 | 19,760 | 77,460 |
| Concrete | 740 | 1,650 | 6,000 |
| Labor | 12,290 | 31,240 | 117,630 |
| Pipe and Valves | 1,300 | 3,600 | 14,100 |
| SUBTOTAL | 32,680 | 56,600 | 216,590 |
| Miscellaneous and Contingency | 4,900 | 8,490 | 32,490 |
| TOTAL | 37,580 | 65,090 | 249,080 |



CONSTRUCTION COST
OFF-SITE REGIONAL CARBON REGENERATION
HANDLING AND TRANSPORTATION

FIGURE 20

A summary of the operation and maintenance requirements is presented in Table 29, and they are also shown in Figures 21 and 22. The total costs represent the labor, energy, and maintenance requirements related only to the handling and transportation of activated carbon. The costs do not include the cost of regeneration at the regional regeneration facility.

Table 29

Operation and Maintenance Summary

Off-Site Regional Carbon Regeneration

Handling and Transportation

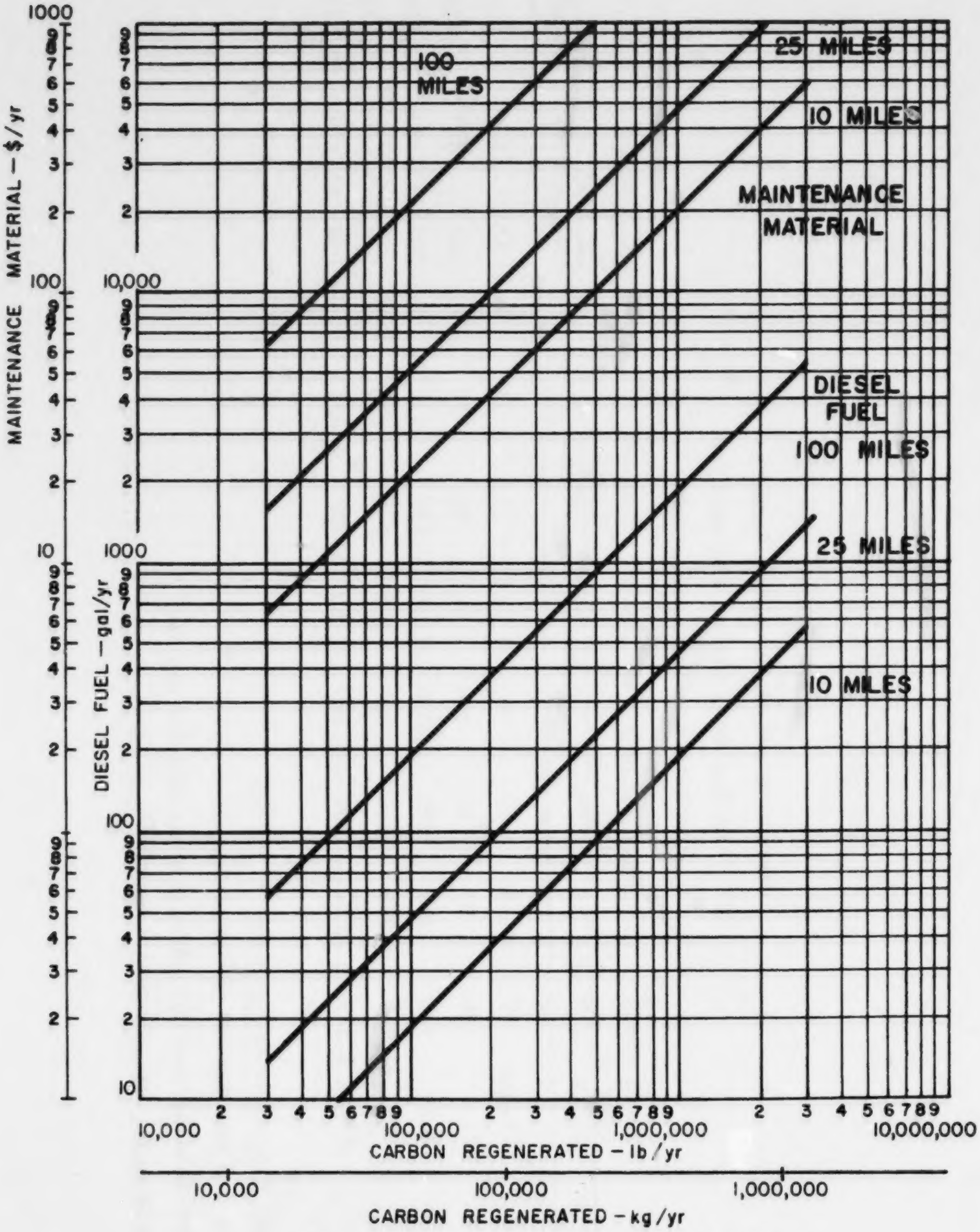
| Carbon Regenerated lbs/yr | Diesel Fuel[1] gals/yr | | | Maintenance Matls-$/yr | | | Labor[2] hrs/yr | | | Total Cost[3] $/yr | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 mi | 25 mi | 100 mi | 10 mi | 25 mi | 100 mi | 10 mi | 25 mi | 100 mi | 10 mi | 25 mi | 100 mi |
| 30,000 | 5.7 | 14.3 | 57 | 6 | 20 | 60 | 6.8 | 11 | 14 | 80 | 130 | 230 |
| 150,000 | 28.6 | 71.4 | 286 | 30 | 80 | 300 | 34 | 55 | 70 | 380 | 660 | 1,130 |
| 500,000 | 97 | 243 | 971 | 100 | 260 | 1,020 | 116 | 187 | 238 | 1,310 | 2,230 | 3,840 |
| 1,000,000 | 194 | 486 | 1,943 | 200 | 510 | 2,040 | 232 | 374 | 476 | 2,610 | 4,470 | 7,670 |
| 3,000,000 | 582 | 1,430 | 5,829 | 610 | 1,530 | 6,120 | 780 | 1,200 | 1,428 | 8,670 | 14,170 | 23,020 |

NOTE: All distances are one way

[1] Based on 3.5 mpg for 30 $yd^3$ semi-dump

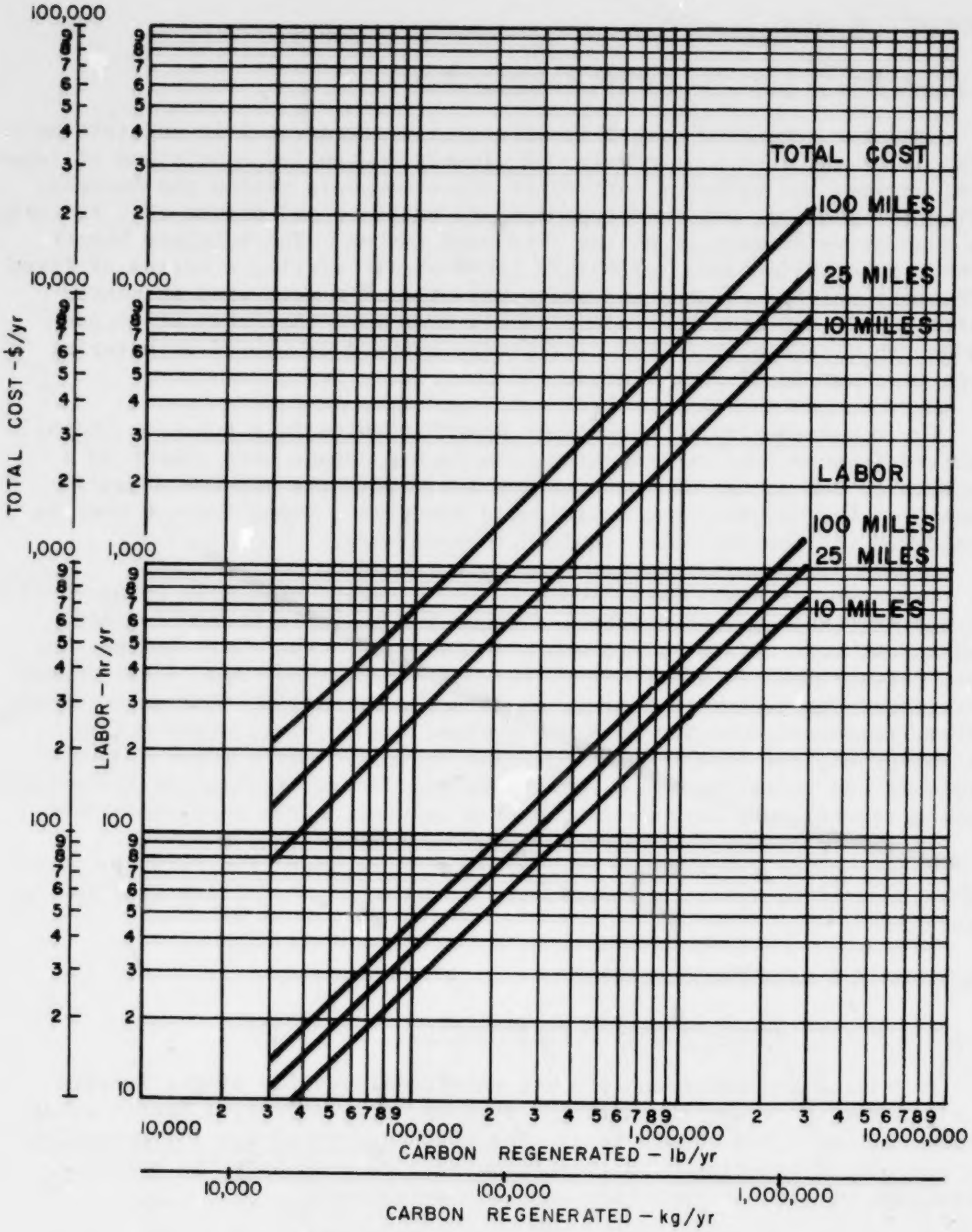
[2] Labor for loading and unloading carbon and for hauling

[3] Calculated using diesel fuel at $0.45/gallon and labor at $10.00/hour



OPERATION AND MAINTENANCE
OFF-SITE REGIONAL CARBON REGENERATION
HANDLING AND TRANSPORTATION

FIGURE 21



OPERATION AND MAINTENANCE
OFF-SITE REGIONAL CARBON REGENERATION
HANDLING AND TRANSPORTATION

FIGURE 22

## CONSTRUCTION COST

### Multiple Hearth Granular Carbon Regeneration

Granular activated carbon is effectively regenerated in multiple hearth furnaces by exposure to properly and closely-controlled conditions of temperature, oxygen, and moisture content of the atmosphere within the furnace. During the process, adsorbed organics are oxidized and driven off, restoring the adsorptive properties of the activated carbon. The multiple hearth furnace is a cylindrical refractory lined shell carrying a series of fired refractory hearths located one above the other. A revolving insulated central shaft and attached radial rabble arms move the material across the hearth directing material alternately outward or inward as material drops from one level to the next.

The required size of a multiple hearth furnace is a function of the required frequency of regeneration, the carbon dosage used (which is a function of the nature of the organics adsorbed), the allowable hearth loading of the furnace, and anticipated downtime. These factors must be considered in selecting the required furnace size.

Construction costs were developed for a series of single furnaces with various hearth areas. Conceptual designs for multiple hearth furnaces used in the cost estimates are shown in Table 30. The costs include the basic furnace, center shaft drive, furnace and cooling fans, spent carbon storage and dewatering equipment, auxiliary fuel system, exhaust scrubbing system, regenerated carbon handling system, quench tank, steam boiler, control panel, and instrumentation. The equipment costs which are on a furnished and installed basis, were obtained from equipment manufacturers. Housing requirements were developed from manufacturer's recommendations.

Construction costs for a complete carbon regeneration furnace and supporting equipment are presented in Table 31 and illustrated in Figure 23.

## OPERATION AND MAINTENANCE COST

### Multiple Hearth Granular Carbon Regeneration

Operation and maintenance costs were developed for single furnace multiple hearth carbon regeneration systems, with effective hearth areas between 27 and 1,509 square feet. The costs presented are for operation 100 percent of the time, and correction must be made once the actual percentage of time in operation has been determined.

Process electrical energy requirements were developed from manufacturer's information listing connected and operating horsepower requirements for furnaces of various sizes, and assuming the furnace operates 100 percent of the time. Appropriate correction must be made for the actual percentage of the time, that the furnace is operated. Building energy requirements are only for lighting and ventilation.

## Table 30

### Multiple Hearth Granular Carbon Regeneration Conceptual Design

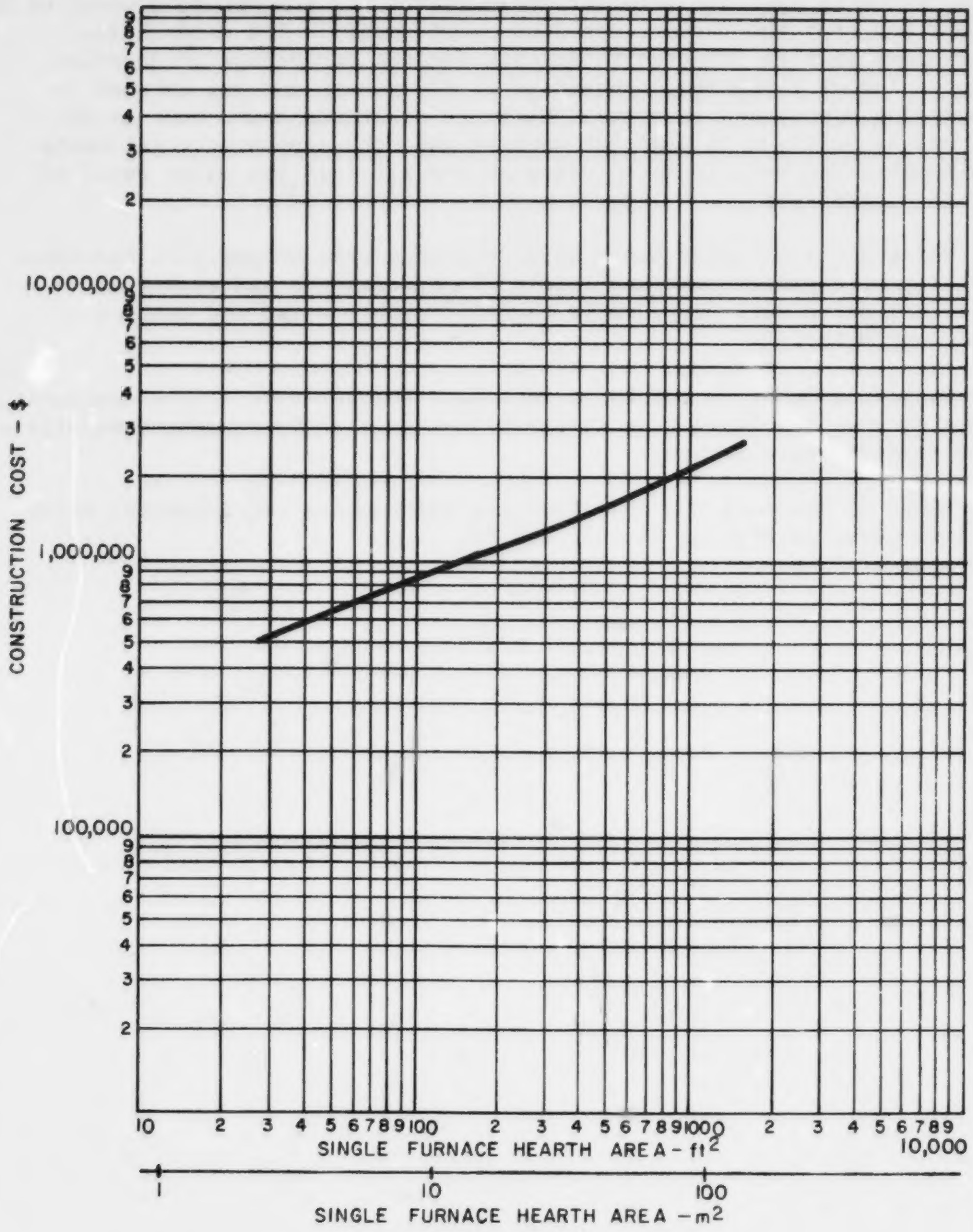
| Furnace Configuration | | | |
|---|---|---|---|
| Effective Hearth Area - Sq. Ft. | I.D. | No. Hearths | Building Area Requirements, $ft^2$ |
| 27 | 30" | 6 | 750 |
| 37 | 30" | 6 | 750 |
| 147 | 39" | 6 | 900 |
| 359 | 10'-6" | 5 | 1,200 |
| 732 | 14'-6" | 6 | 1,800 |
| 1,509 | 20'-0" | 6 | 2,400 |

## Table 31

## Construction Cost

## Multiple Hearth Granular Carbon Regeneration

| Furnace Hearth Area - Square Feet | 27 | 37 | 147 | 359 | 732 | 1,509 |
|---|---|---|---|---|---|---|
| Manufactured Equipment | $208,000 | $260,000 | $490,000 | $610,000 | $980,000 | $1,230,000 |
| Labor | 112,000 | 140,000 | 260,000 | 330,000 | 530,000 | 670,000 |
| Pipe and Valves | 7,840 | 7,840 | 7,840 | 13,620 | 22,060 | 45,910 |
| Electrical and Instrumentation | 7,920 | 7,970 | 7,970 | 8,780 | 14,260 | 25,770 |
| Housing | 102,400 | 102,400 | 116,000 | 163,500 | 229,500 | 312,300 |
| SUBTOTAL | 438,160 | 518,210 | 881,810 | 1,125,900 | 1,775,620 | 2,283,980 |
| Miscellaneous and Contingency | 65,720 | 77,730 | 132,270 | 168,890 | 226,340 | 342,600 |
| TOTAL | $503,880 | $595,940 | $1,014,080 | $1,294,790 | $2,041,960 | $2,626,580 |



CONSTRUCTION COST
MULTIPLE HEARTH GRANULAR CARBON REGENERATION

FIGURE 23

Natural gas requirements were calculated from manufacturer's recommendations, assuming that the feed activated carbon has a moisture content of 50 percent and that the furnace operates continuously. The natural gas requirement must be adjusted to account for the percentage of downtime. A heat value of 1,000 Btu/standard cu ft of natural gas was assumed in determining energy requirements. Where an alternate fuel, such as No. 2 Fuel Oil is utilized in place of natural gas, the appropriate gallonage requirements can be calculated using an overall fuel Btu value equal to that of natural gas.

Maintenance material costs were developed from information furnished by equipment suppliers and are related to maintenance and repair of electrical drive machinery, replacement of rabble arms, and damaged refractory materials.

Operating labor is related principally to operation of the equipment. Estimates were developed from information furnished by equipment suppliers and operating installations.

Table 32 presents the operation and maintenance requirements, which are also shown in Figures 24, 25, and 26.

## Table 32

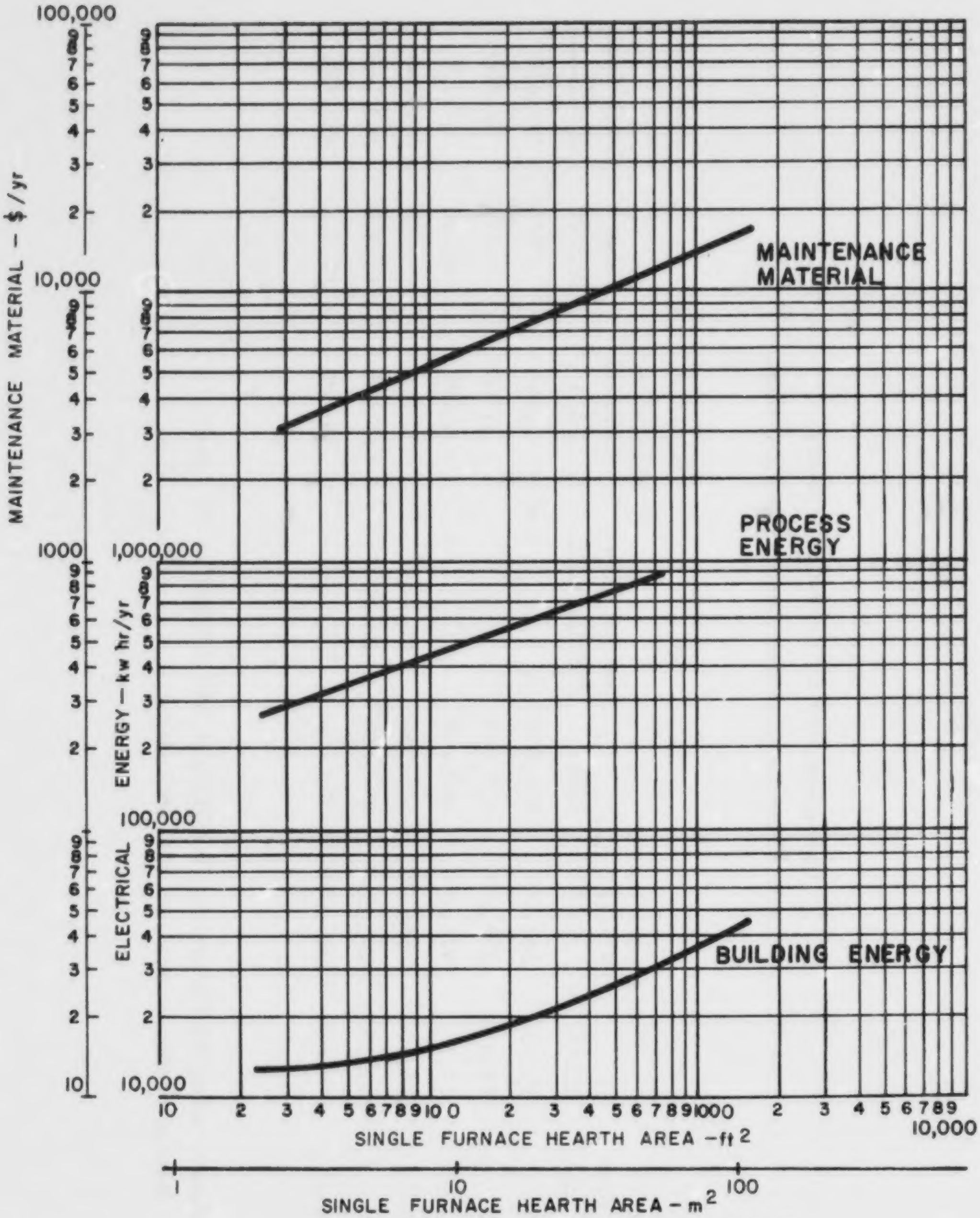
Operation and Maintenance Summary

Multiple Hearth Granular Carbon Regeneration

| Effective Hearth Area sq. ft. | Electrical Energy kw-hr/yr |  |  | Natural Gas scf/yr x $10^6$ | Maintenance Material $/yr | Labor hrs/yr | Total Cost $/yr* |
|---|---|---|---|---|---|---|---|
|  | Building | Process | Total |  |  |  |  |
| 27 | 14,630 | 261,400 | 276,030 | 5.80 | 2,800 | 900 | 27,620 |
| 37 | 14,630 | 326,750 | 341,380 | 7.72 | 3,500 | 950 | 32,840 |
| 147 | 17,550 | 424,770 | 442,320 | 26.2 | 6,000 | 3,400 | 87,330 |
| 359 | 23,400 | 588,150 | 611,550 | 48.26 | 8,000 | 6,200 | 151,080 |
| 732 | 35,100 | 849,550 | 884,650 | 108.40 | 11,000 | 10,500 | 283,460 |
| 1,509 | 46,800 | 1,307,000 | 1,353,800 | 207.75 | 15,000 | 17,000 | 495,690 |

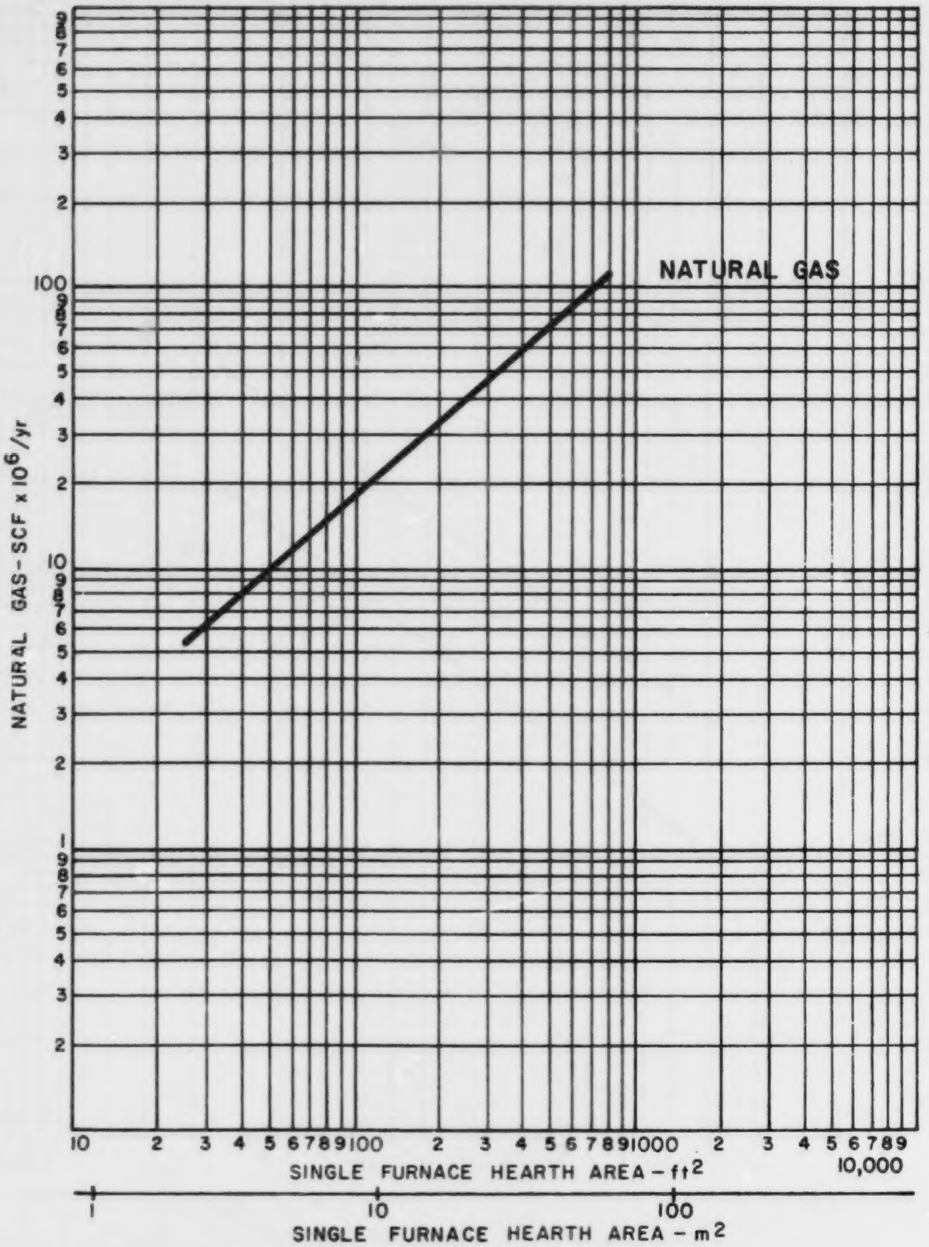
*Calculated using $0.03/kw-hr, $0.0013/scf and $10.00/hr of labor

NOTE: Makeup carbon costs are not included



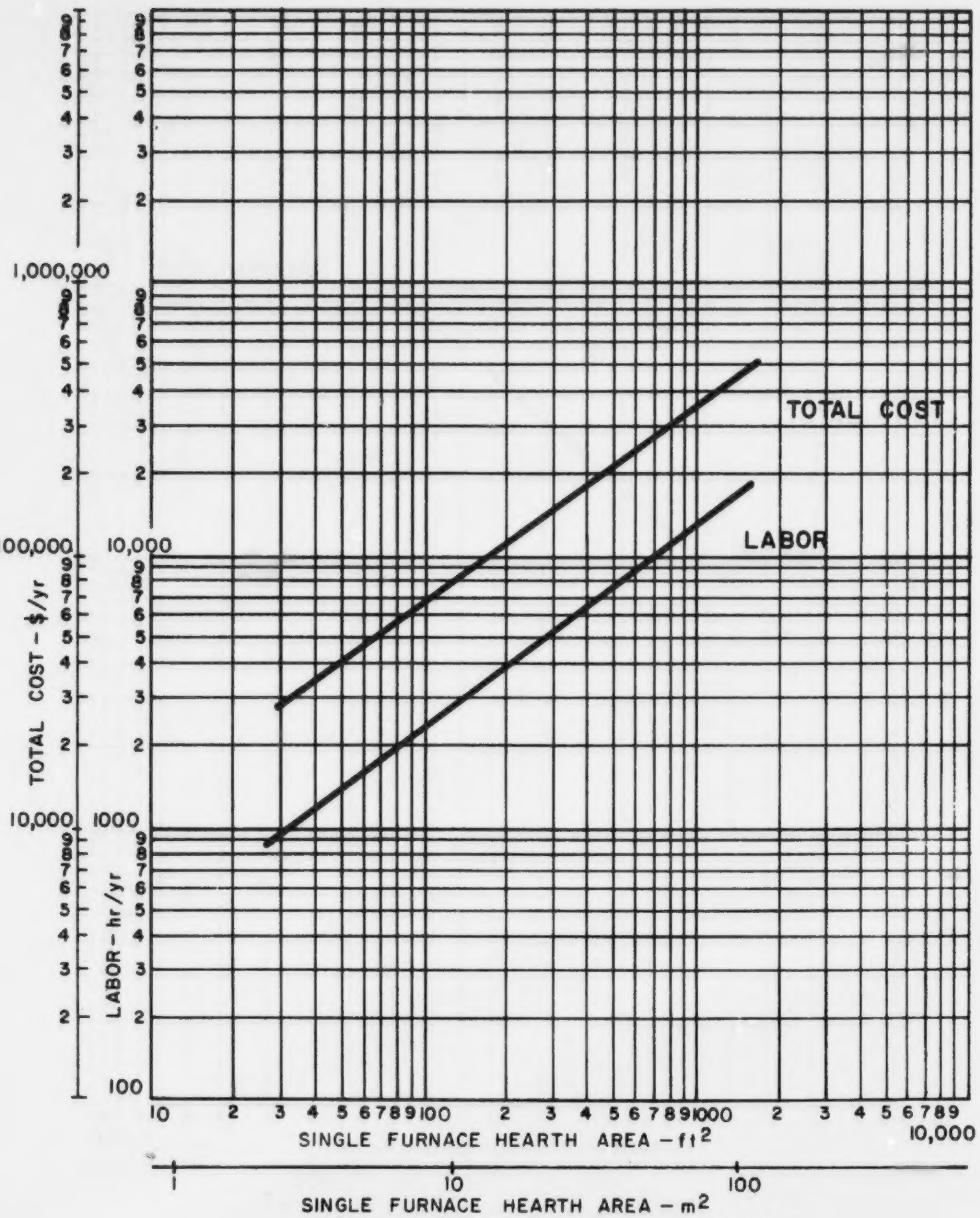
OPERATION AND MAINTENANCE
MULTIPLE HEARTH GRANULAR CARBON REGENERATION

FIGURE 24



OPERATION AND MAINTENANCE
MULTIPLE HEARTH GRANULAR CARBON REGENERATION

FIGURE 25



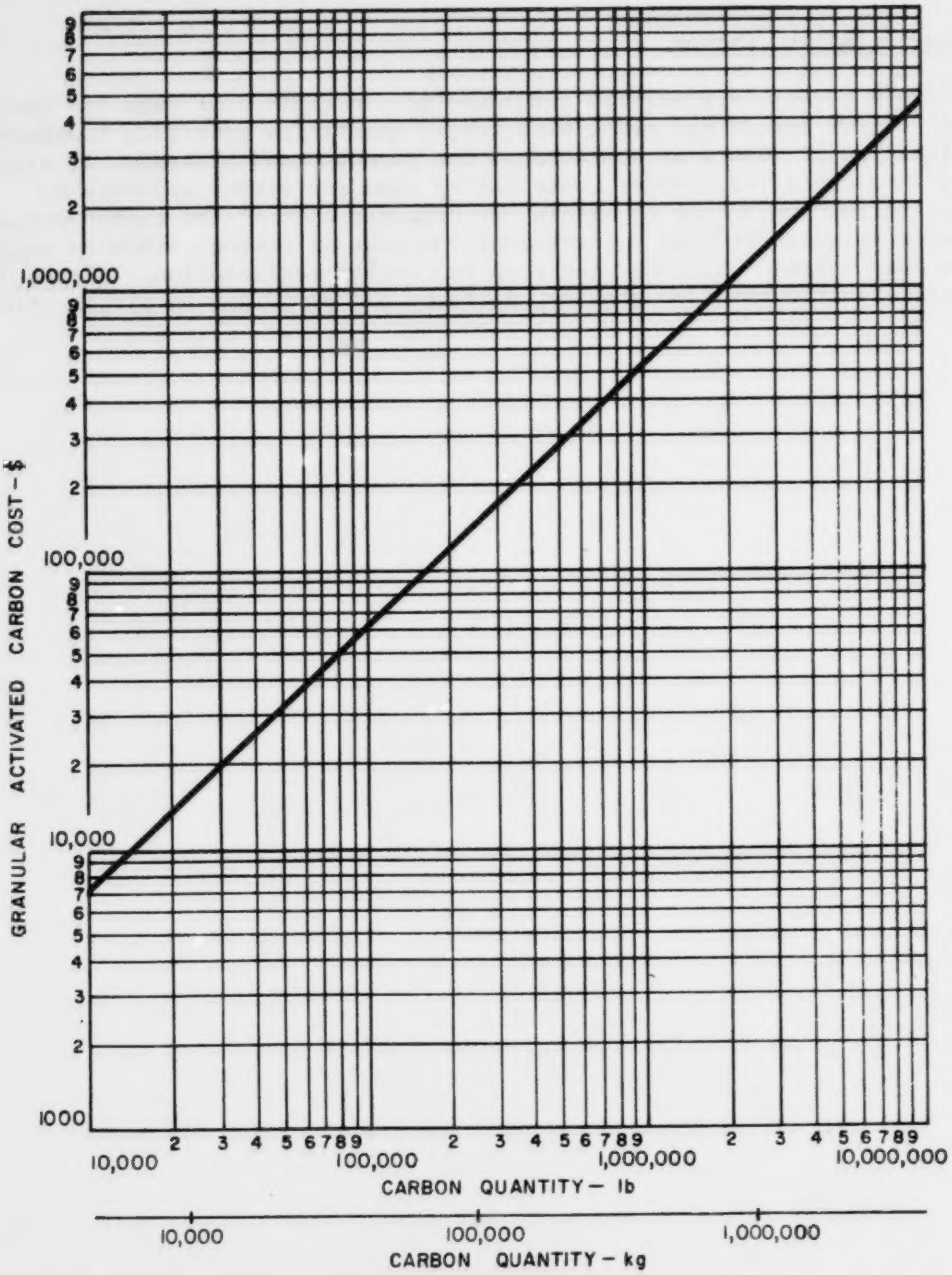
OPERATION AND MAINTENANCE
MULTIPLE HEARTH GRANULAR CARBON REGENERATION

FIGURE 26

## MATERIAL COST

### Granular Activated Carbon

Virgin carbon is generally purchased in two cubic foot bags for quantities of 40,000 pounds and less, with larger quantities generally transported in bulk by rail. Costs were developed for purchase and placement of virgin carbon in a contactor. These costs may be used for either pressure or gravity carbon contactors to obtain the complete cost of the carbon contactor. The curve may also be used to determine the cost of makeup carbon to replace carbon lost during contactor operation and carbon regeneration. Figure 27 presents a cost curve for purchase, delivery and placement of virgin carbon.



MATERIAL COST
GRANULAR ACTIVATED CARBON

FIGURE 27

## CONSTRUCTION COST

### Chlorine Storage and Feed Systems

The costs for chlorine feed facilities have been based upon use of 150 pound cylinders for feed rates up to 100 pounds per day and ton cylinders for feed rates up to 2,000 pounds per day. For rates of 2,000 pounds per day and greater, three options were considered: (1) ton cylinders; (2) on-site storage with bulk rail delivery; and (3) direct feed from a rail car.

### Cylinder Storage

The maximum chlorinator capacity utilized was 8,000 pounds per day and one standby chlorinator was included for each installation. The costs include cylinder scales for all installations, and evaporators are included for delivery rates of 2,000 pounds per day and greater. Residual analyzers with flow proportioning controls were included for flow rates greater than 1,000 pounds per day. Costs were also included for injector pumps capable of delivering sufficient water at 25 psi to allow production of a 3,500 mg/l high strength solution. Housing cost includes both the chlorinator room and the cylinder storage room. All cylinders were assumed to be stored indoors, and the number of days of storage ranged from 15 for the smallest installation to 7 for the largest. The larger the chlorine usage, presumably the closer the plant would be to chlorine distribution centers, and less chlorine would have to be maintained at the plant. For feed rates greater than 100 pounds per day, electrically operated, monorail trolley hoists were included.

### On-Site Storage Tank with Rail Delivery

Use of an on-site storage tank would eliminate the housing requirement for cylinder storage, the monorail and hoist, the cylinder scale, cylinder trunnions and the cylinder manifold piping. However, additive costs are incurred for the tank and its supports, a tank sun shield, load cells for the tank, a railhead connection and associated track, unloading platform, an air padding system, expansion tanks, and miscellaneous gauges, switches and piping. All considerations relating to the chlorinators, evaporators, and other feed equipment remain the same as for the ton cylinder curve. The amount of chlorine storage provided with the on-site tank is 15 days, which is greater than feeding from ton cylinders at the same flow rate, principally because space is not a problem and delivery of a tank car by rail is often less reliable than delivery of ton cylinders by truck.

The rail siding costs include the cost of a turnout from the main line, 500 feet of on-site track, and the unloading platform. Piping costs would be strongly influenced by the location of the storage tank relative to the chlorinators. Normally the storage tank is located near the plant boundary. Valving is more complex than with ton cylinders, mainly due to the unloading system, the use of duplicate heads for gas or liquid feed, and the air padding system.

This curve may be adapted to bulk truck delivery by removing the cost of the rail siding.

### Direct Feed from Rail Car

Chlorine may be fed directly from the rail car to the evaporator, eliminating the requirement for an on-site storage tank. Ownership of the rail car may be by the utility or the chlorine manufacturer. In the later case, a higher cost per ton of chlorine must be paid to account for amortization and maintenance costs of the car. Chlorinator, evaporator and other feed equipment costs are the same as for feed from ton cylinders. Rail siding costs are the same as for on-site storage with rail delivery.

Estimated construction costs are shown in Tables 33, 34, and 35 for feed systems between 10 and 10,000 pounds per day, and the costs are shown graphically in Figure 28. As may be seen, construction costs for on-site storage are not significantly greater than costs for use of ton cylinders. However, the chlorine cost would be significantly less when it is delivered in bulk.

## OPERATION AND MAINTENANCE COST

### Chlorine Storage and Feed Systems

Power requirements include heating, lighting, and ventilation of the chlorination building and the cylinder storage area, the electrical hoist when ton cylinders are used, evaporators when feed is 2,000 pounds/day or greater and the injector pump for the high strength chlorine solution. This pump was sized to deliver sufficient flow for a maximum chlorine concentration of 3,500 mg/l in the high strength solution. Where on-site storage tanks were utilized, the electrical hoist power requirements are eliminated and heating, ventilating, and lighting power are significantly reduced due to elimination of indoor storage facilities.

Maintenance material requirements were based upon experience at operating plants, and are essentially the same for use of cylinders on-site storage, or rail car storage and feed. Cost of chlorine is not included in the maintenance material estimates.

Labor requirements for cylinders were based upon loading and unloading cylinders from a delivery truck, time to connect and disconnect cylinders from the chlorine headers, and the time for routine daily checking of the cylinders. For on-site tank storage, labor consists of time to unload a bulk delivery truck or rail tanker. The rail car storage concept requires labor only to move the rail car into place, and to connect and disconnect the cars from the feed system. Common to all installations would be the time required for daily checking and periodic maintenance of the chlorine handling system.

Table 33

Construction Cost

Chlorine Storage and Feed Systems - Cylinder Storage

| | Chlorine Feed Capacity - Pounds/day | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 500 | 1,000 | 2,000 | 5,000 | 10,000 |
| Manufactured Equipment | $ 3,130 | 10,630 | 19,880 | 31,500 | 36,500 | 54,130 |
| Labor | 2,500 | 2,500 | 3,800 | 6,700 | 6,700 | 7,600 |
| Pipe and Valves | 320 | 1,060 | 1,750 | 2,540 | 5,190 | 9,020 |
| Electrical and Instrumentation | 1,000 | 2,400 | 2,800 | 5,000 | 7,200 | 9,500 |
| Housing | 3,900 | 12,300 | 15,700 | 18,400 | 25,900 | 45,700 |
| SUBTOTAL | 10,850 | 28,890 | 43,930 | 64,140 | 81,490 | 125,950 |
| Miscellaneous and Contingency | 1,630 | 4,330 | 6,590 | 9,620 | 12,220 | 18,890 |
| TOTAL | $ 12,480 | 33,220 | 50,520 | 73,760 | 93,710 | 144,840 |

## Table 34

### Construction Cost

### Chlorine Storage and Feed Systems

### On-Site Storage Tank With Rail Delivery

| | Chlorine Feed Capacity Pounds/day | | |
|---|---|---|---|
| | 2,000 | 5,000 | 10,000 |
| Manufactured Equipment | | | |
| Equipment | $ 46,400 | 58,540 | 80,590 |
| Rail Siding | 48,410 | 48,410 | 48,410 |
| Steel | 1,380 | 2,200 | 3,080 |
| Labor | 8,560 | 10,250 | 12,560 |
| Pipe and Valves | 5,080 | 10,380 | 18,040 |
| Electrical and Instrumentation | 12,400 | 16,710 | 21,130 |
| Housing | 7,410 | 7,410 | 8,580 |
| SUBTOTAL | 129,640 | 153,900 | 192,390 |
| Miscellaneous and Contingency | 19,450 | 23,090 | 28,860 |
| TOTAL | $ 149,090 | 176,990 | 221,260 |

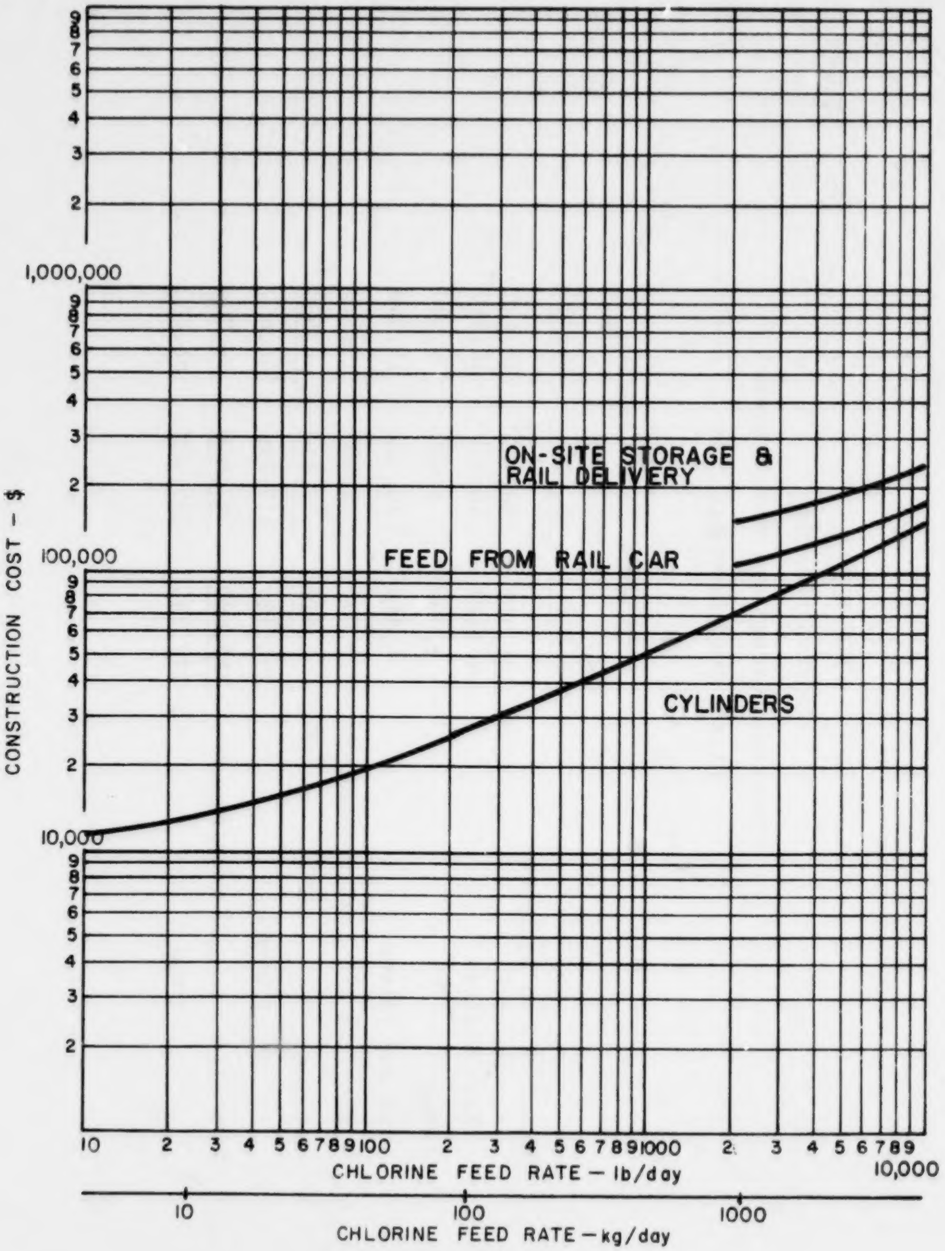
## Table 35

## Construction Cost

## Chlorine Storage and Feed Systems

## Direct Feed From Rail Car

| | Chlorine Feed Capacity Pounds/day | | |
|---|---|---|---|
| | 2,000 | 5,000 | 10,000 |
| Manufactured Equipment | | | |
| Equipment | $ 31,500 | 36,500 | 54,130 |
| Rail Siding | 48,410 | 48,410 | 48,410 |
| Labor | 7,000 | 8,000 | 9,000 |
| Pipe and Valves | 4,810 | 10,100 | 17,040 |
| Electrical and Instrumentation | 5,000 | 7,200 | 9,500 |
| Housing | 7,410 | 7,410 | 8,580 |
| SUBTOTAL | 104,130 | 117,620 | 146,660 |
| Miscellaneous and Contingency | 15,620 | 17,640 | 22,000 |
| TOTAL | $ 119,750 | 135,260 | 168,660 |



CONSTRUCTION COST
CHLORINE STORAGE AND FEED SYSTEMS

FIGURE 28

Figures 29 and 30 present operation and maintenance curves for chlorine feed systems using cylinder storage. For feed rates greater than 2,000 pounds per day, and use of a on-site storage tank with rail delivery or the rail car storage and feed, operation and maintenance requirements are shown in Figures 31 and 32. Table 36 presents a summary of operation and maintenance requirements for all three storage concepts.

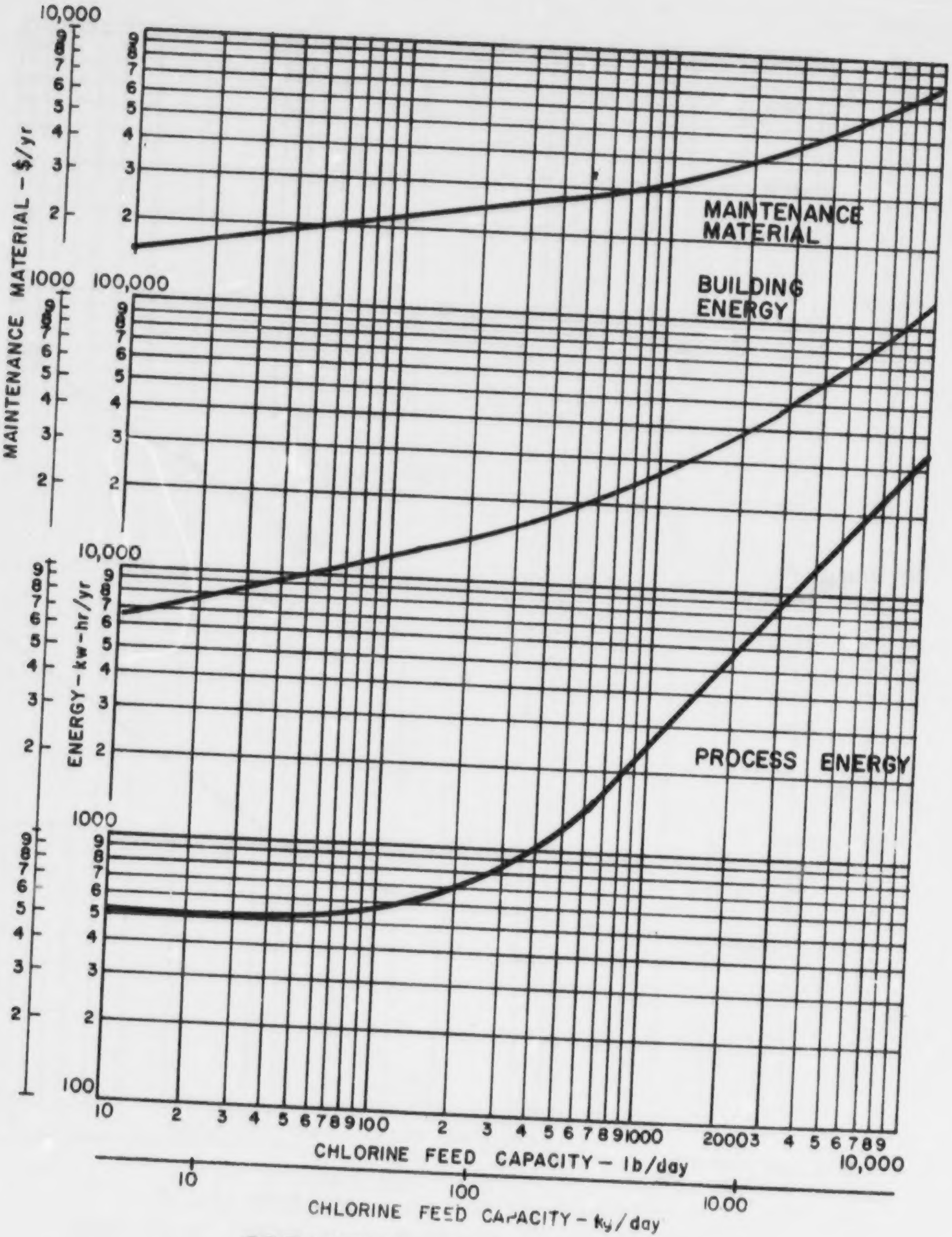
## Table 36

## Operation and Maintenance Summary

## Chlorine Feed Systems

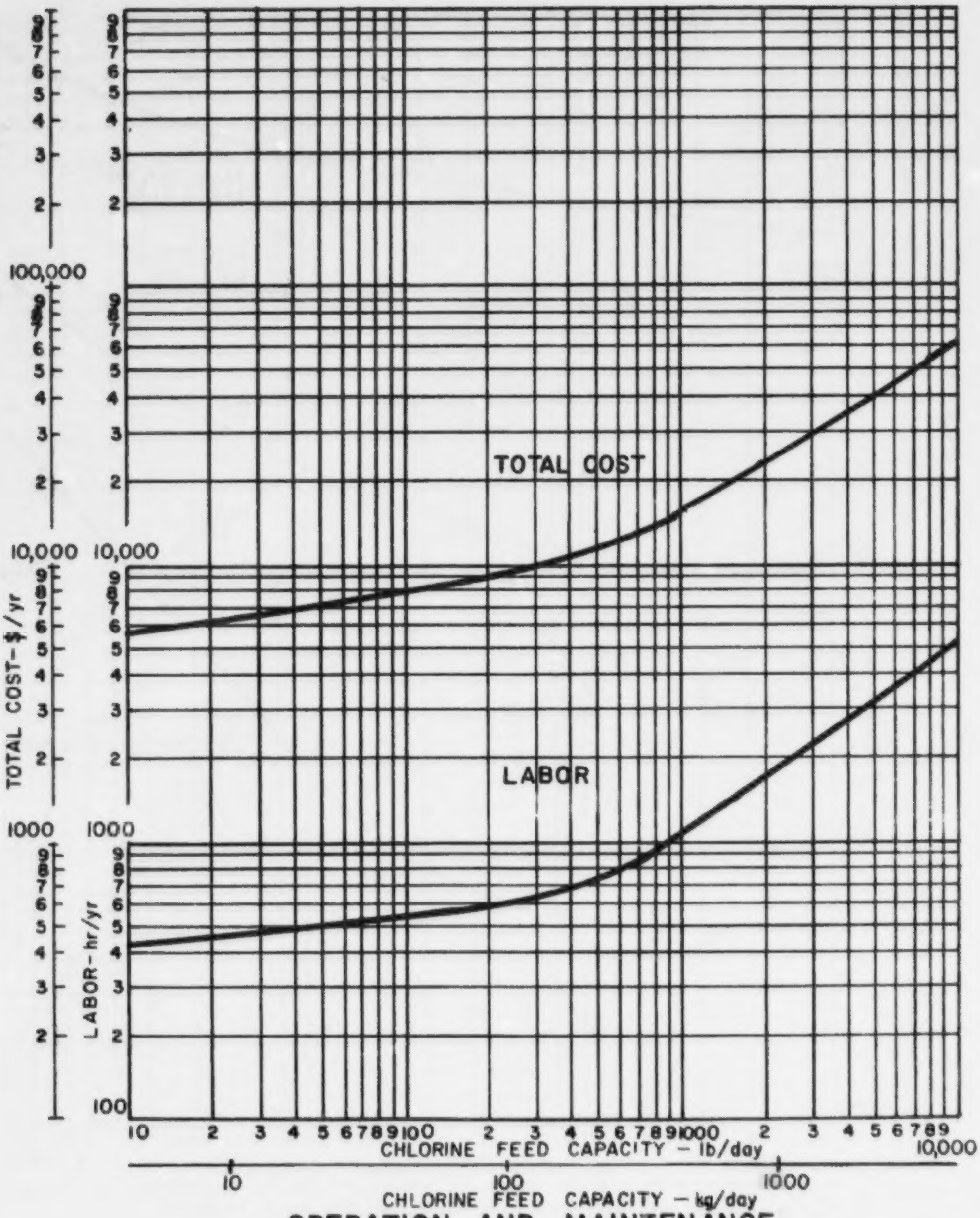
| Feed Rate - lb/day | | Energy kw-hr/yr | | | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|---|
| | | Building | Process | Total | | | |
| 10 | Cylinder Storage | 6,160 | 570 | 6,730 | 1,430 | 437 | 6,000 |
| 500 | | 22,570 | 1,120 | 23,690 | 2,860 | 663 | 10,200 |
| 1,000 | | 25,650 | 2,230 | 27,880 | 3,300 | 1,267 | 16,810 |
| 2,000 | | 41,040 | 6,210 | 47,250 | 4,400 | 2,043 | 26,250 |
| 5,000 | | 65,660 | 15,530 | 81,190 | 5,500 | 3,140 | 39,340 |
| 10,000 | | 123,120 | 30,990 | 154,110 | 7,700 | 5,443 | 66,750 |
| 2,000 | On-Site Storage Rail Delivery | 10,260 | 1,740 | 12,000 | 4,400 | 926 | 14,020 |
| 5,000 | | 10,260 | 4,340 | 14,600 | 5,500 | 1,100 | 16,940 |
| 10,000 | | 15,390 | 8,690 | 24,080 | 7,700 | 1,144 | 19,860 |
| 2,000 | Direct Feed From Rail Car | 10,260 | 1,740 | 12,000 | 4,400 | 754 | 12,300 |
| 5,000 | | 10,260 | 4,340 | 14,600 | 5,500 | 790 | 13,840 |
| 10,000 | | 10,260 | 8,690 | 24,080 | 7,700 | 796 | 16,380 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



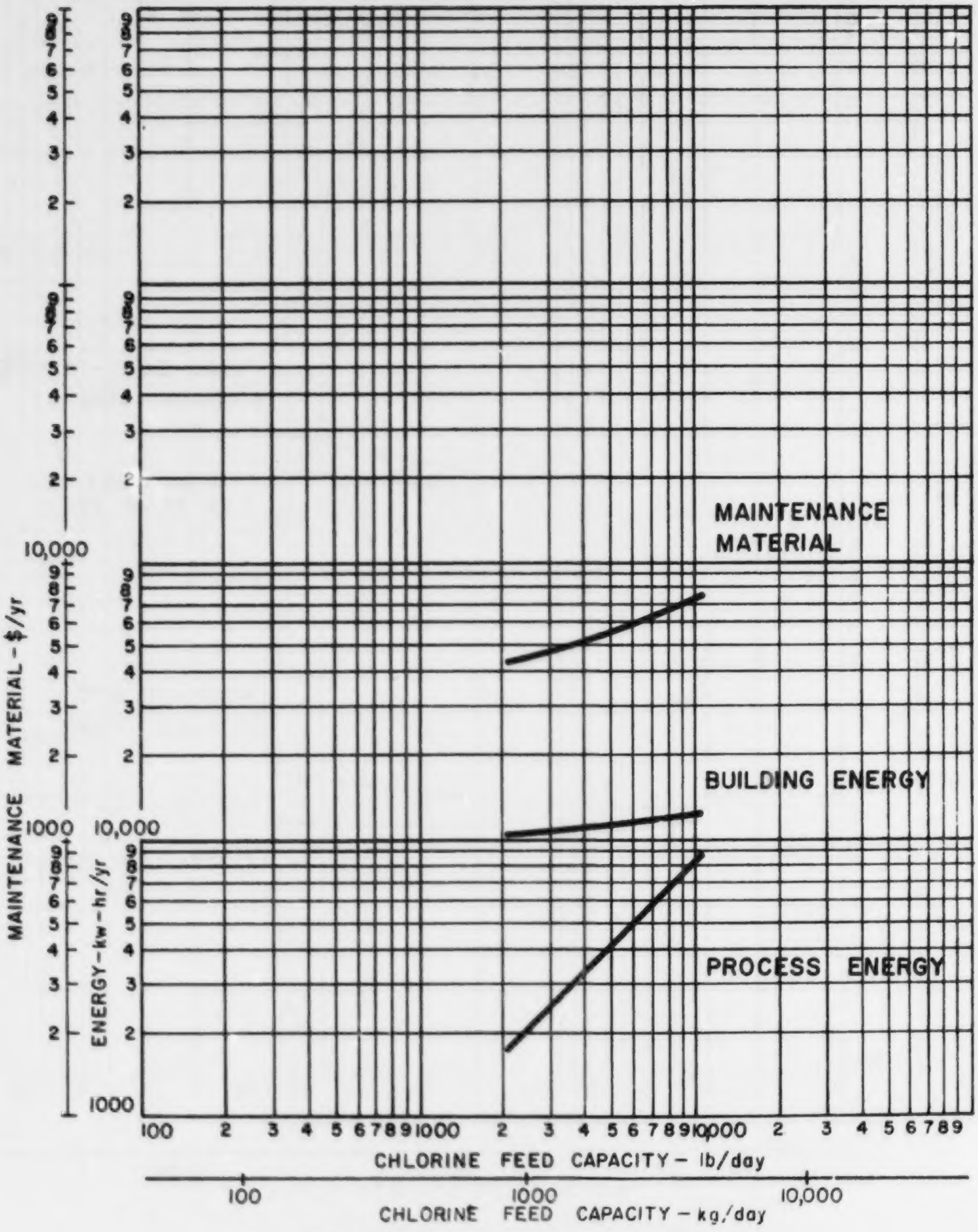
OPERATION AND MAINTENANCE
CHLORINE STORAGE AND FEED SYSTEMS
CYLINDER STORAGE

FIGURE 29



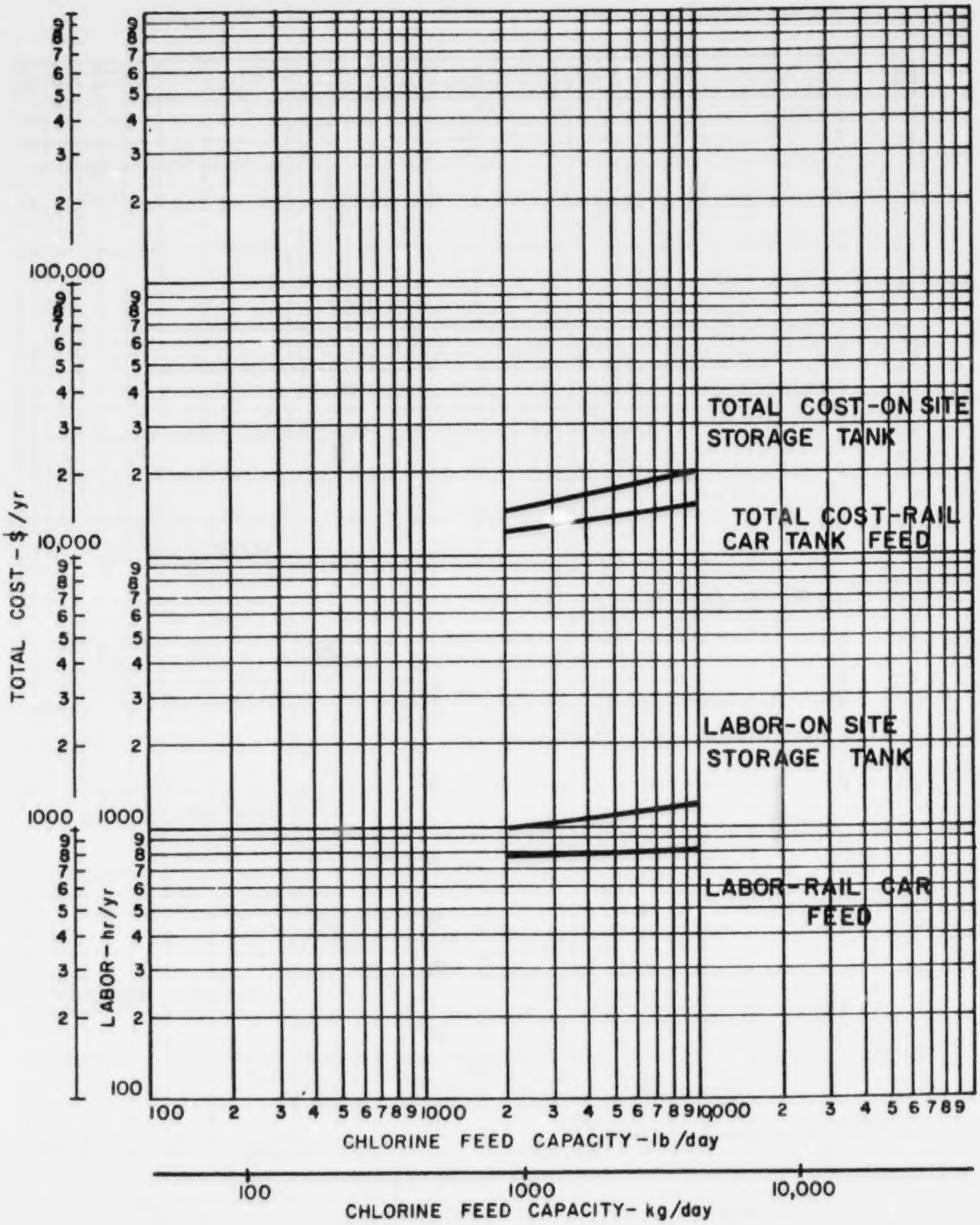
OPERATION AND MAINTENANCE
CHLORINE STORAGE AND FEED SYSTEMS
CYLINDER STORAGE

FIGURE 30



OPERATION AND MAINTENANCE
CHLORINE STORAGE AND FEED SYSTEMS
ON-SITE STORAGE TANK AND RAIL CAR FEED

FIGURE 31



OPERATION AND MAINTENANCE
CHLORINE STORAGE AND FEED SYSTEMS
ON-SITE STORAGE TANK AND RAIL CAR FEED
FIGURE 32

## CONSTRUCTION COST

### Ozone Generation Systems and Contact Chambers

Ozone may be generated on-site using either air or pure oxygen. Costs were developed for generation rates between 10 and 3,500 pounds per day. For systems up to 100 pounds per day, air was assumed to be the feed. At generation rates greater than 100 pounds per day, pure oxygen generated on-site is the feed for the ozone generator.

The manufactured equipment cost for ozone generation includes the gas preparation equipment, oxygen generation equipment (at more than 100 pounds per day), the ozone generator, dissolution equipment, electrical and instrumentation costs and all required safety and monitoring equipment. All ozone generating equipment was considered to be housed, but all oxygen generating equipment is located outside on a concrete slab. Construction costs for ozone generating systems are shown in Figure 33 and are presented in Table 37.

The ozone contact chamber is a covered reinforced concrete structure with a depth of 18 feet, and a length to width ratio of approximately 2:1. Partitions are utilized within the chamber to assure uniform flow distribution. Ozone dissolution equipment costs are included within the ozone generation curve costs, and are not included with the ozone contact chamber. Construction costs are shown in Figure 34 and in Table 38.

## OPERATION AND MAINTENANCE COST

### Ozone Generating Systems and Contact Basins

For ozone generation systems less than 100 pounds per day, electrical energy is required for the ozone generator and building heating, cooling and lighting requirements. Ozone generation using air feed requires 11 kw-hr per pound of ozone generated. For larger, oxygen fed systems, the power requirements are 7.5 kw-hr per pound of ozone generated. These figures includes oxygen generation, ozone generation, and ozone dissolution.

Maintenance material requirements are for periodic equipment repair and replacement of parts. Based upon manufacturers recommendations, an annual maintenance material requirement of 1 percent of construction cost was utilized.

Labor requirements are for periodic cleaning of the ozone generating apparatus, maintenance of the oxygen generation equipment, annual maintenance of the contact basin, and day to day operation of the generation equipment.

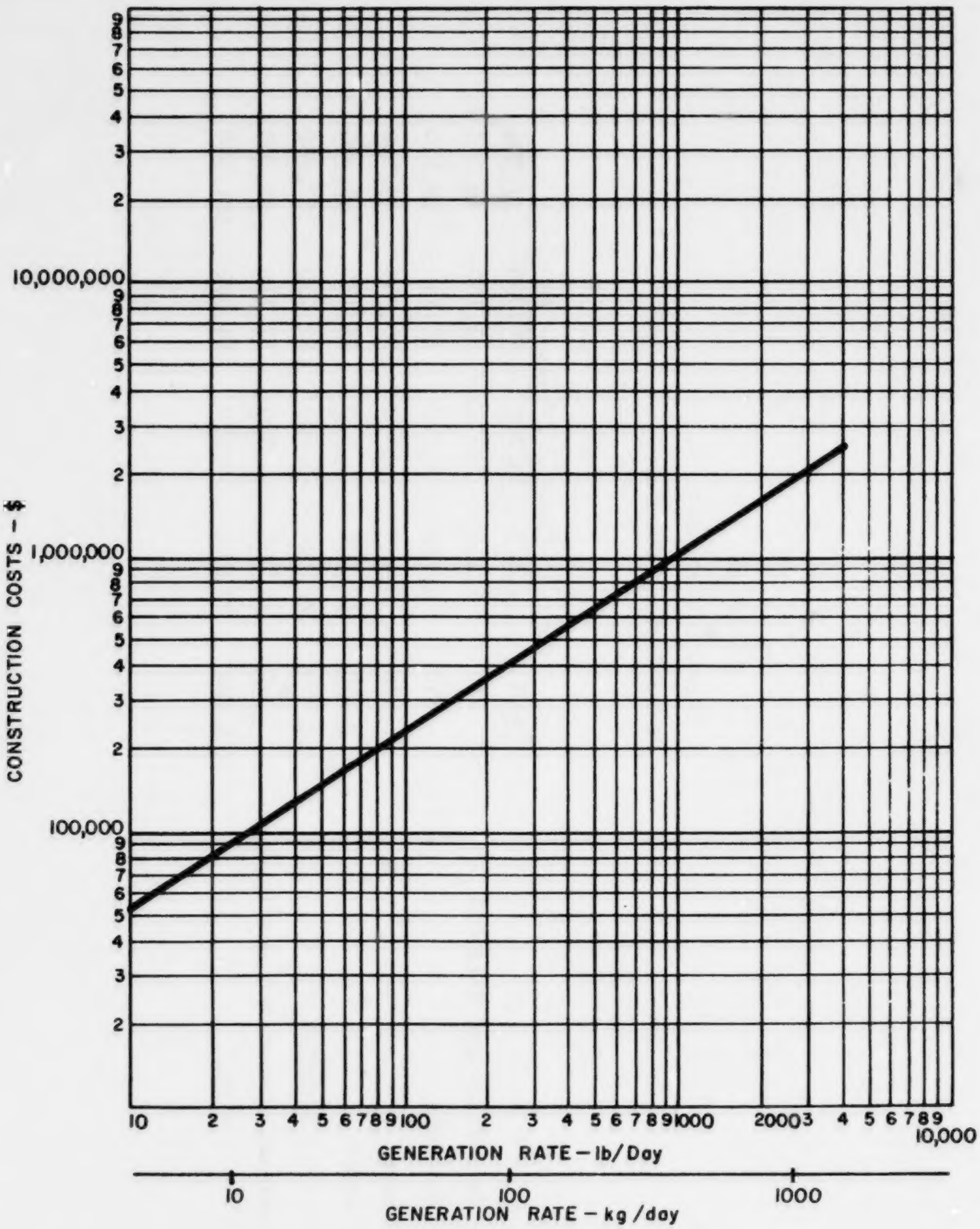
Operation and maintenance requirements are shown in Figures 35 and 36, and are summarized in Table 39.

## Table 37

## Construction Cost

## Ozone Generation Systems

| | Ozone Generation Capacity - Pounds/day | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 100 | 500 | 1,000 | 2,000 | 3,500 |
| Manufactured Equipment | $ 32,250 | 143,610 | 511,960 | 685,810 | 1,070,540 | 1,523,240 |
| Concrete | -- | -- | 1,540 | 1,540 | 2,250 | 2,250 |
| Steel | -- | -- | 1,520 | 1,520 | 2,210 | 2,210 |
| Labor | 4,840 | 33,690 | 114,980 | 143,110 | 207,500 | 272,300 |
| Housing | 6,000 | 8,400 | 12,700 | 23,400 | 35,700 | 41,800 |
| SUBTOTAL | 43,090 | 185,700 | 642,700 | 855,380 | 1,318,200 | 1,841,800 |
| Miscellaneous and Contingency | 6,460 | 27,860 | 96,410 | 128,310 | 197,730 | 276,270 |
| TOTAL | $ 49,550 | 213,560 | 739,110 | 983,690 | 1,515,930 | 2,118,070 |



CONSTRUCTION COST
OZONE GENERATION SYSTEMS

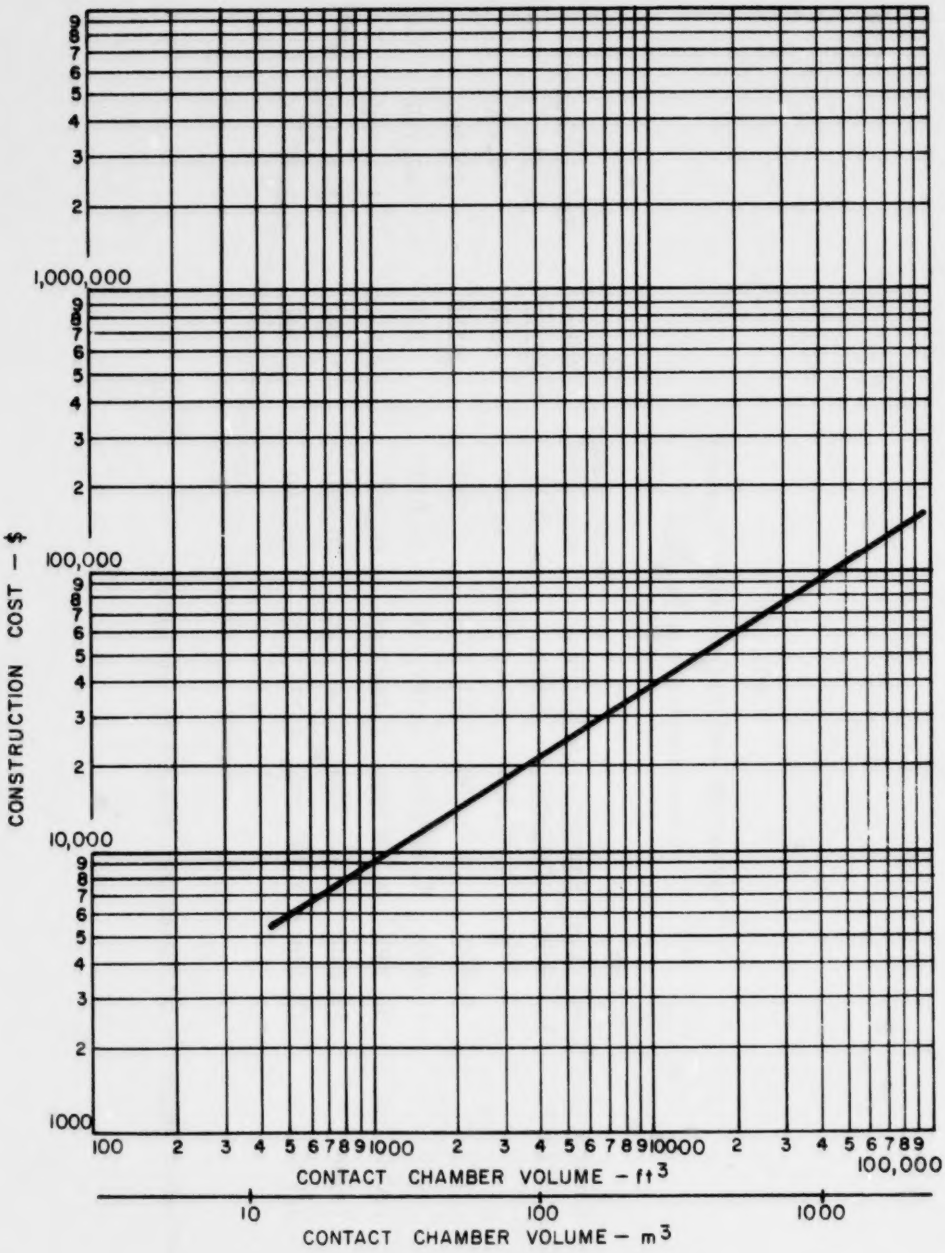
FIGURE 33

Table 38

Construction Cost

Ozone Contact Chamber

| | Contact Chamber Volume - Ft$^3$ | | | | |
|---|---|---|---|---|---|
| | 460 | 4,600 | 23,000 | 46,000 | 92,000 |
| Excavation and Sitework | $ 470 | 1,630 | 2,570 | 5,150 | 10,290 |
| Concrete | 850 | 4,950 | 8,280 | 15,450 | 29,810 |
| Steel | 1,470 | 8,400 | 13,570 | 23,330 | 48,550 |
| Labor | 2,150 | 12,200 | 19,510 | 36,120 | 69,330 |
| SUBTOTAL | 4,940 | 27,180 | 43,930 | 82,050 | 157,980 |
| Miscellaneous and Contingency | 740 | 4,080 | 6,590 | 12,310 | 23,700 |
| TOTAL | $ 5,680 | 31,260 | 50,520 | 94,360 | 181,680 |



CONSTRUCTION COST
OZONE CONTACT BASIN

FIGURE 34

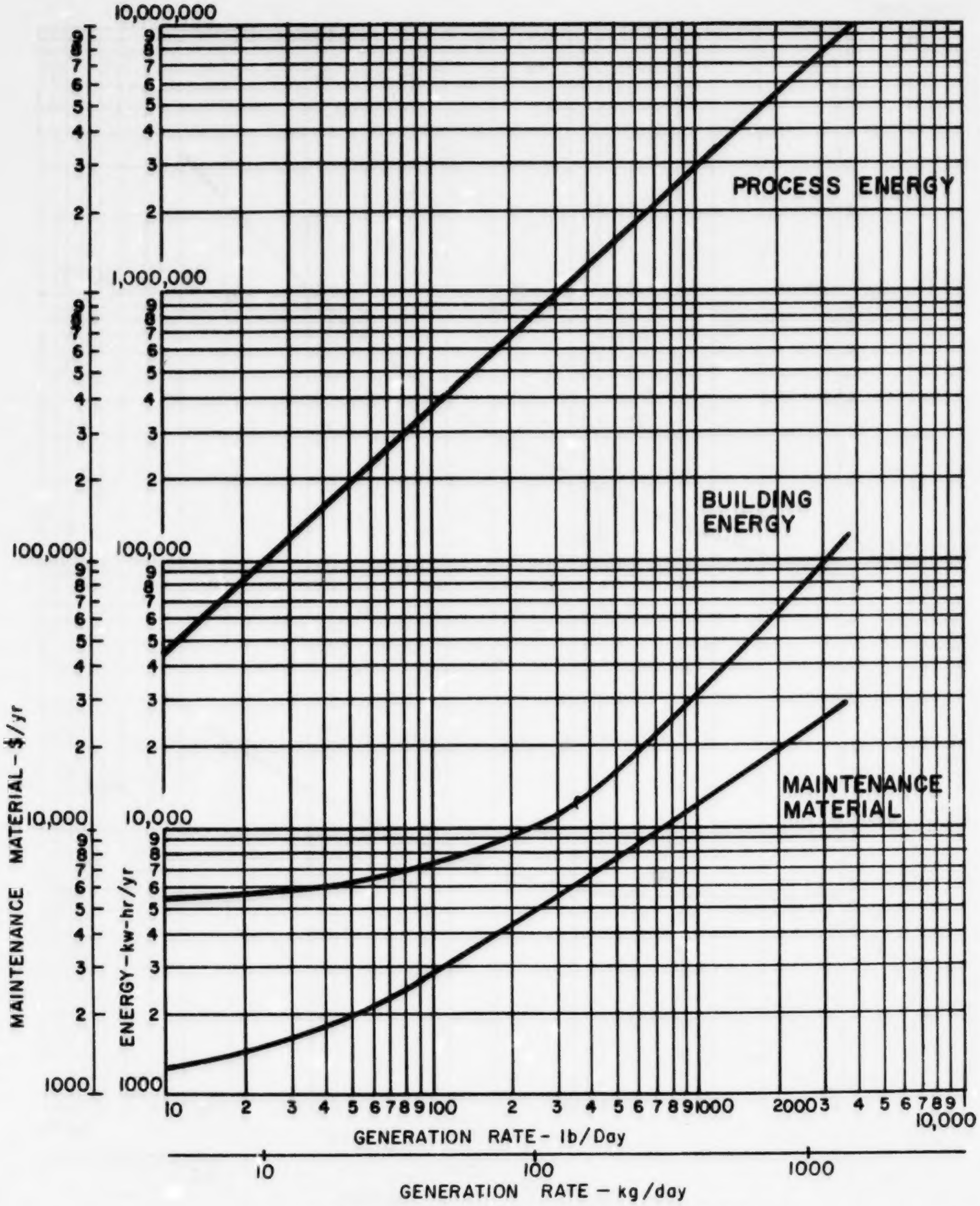
Table 39

Operation and Maintenance Summary

Ozone Generation Systems

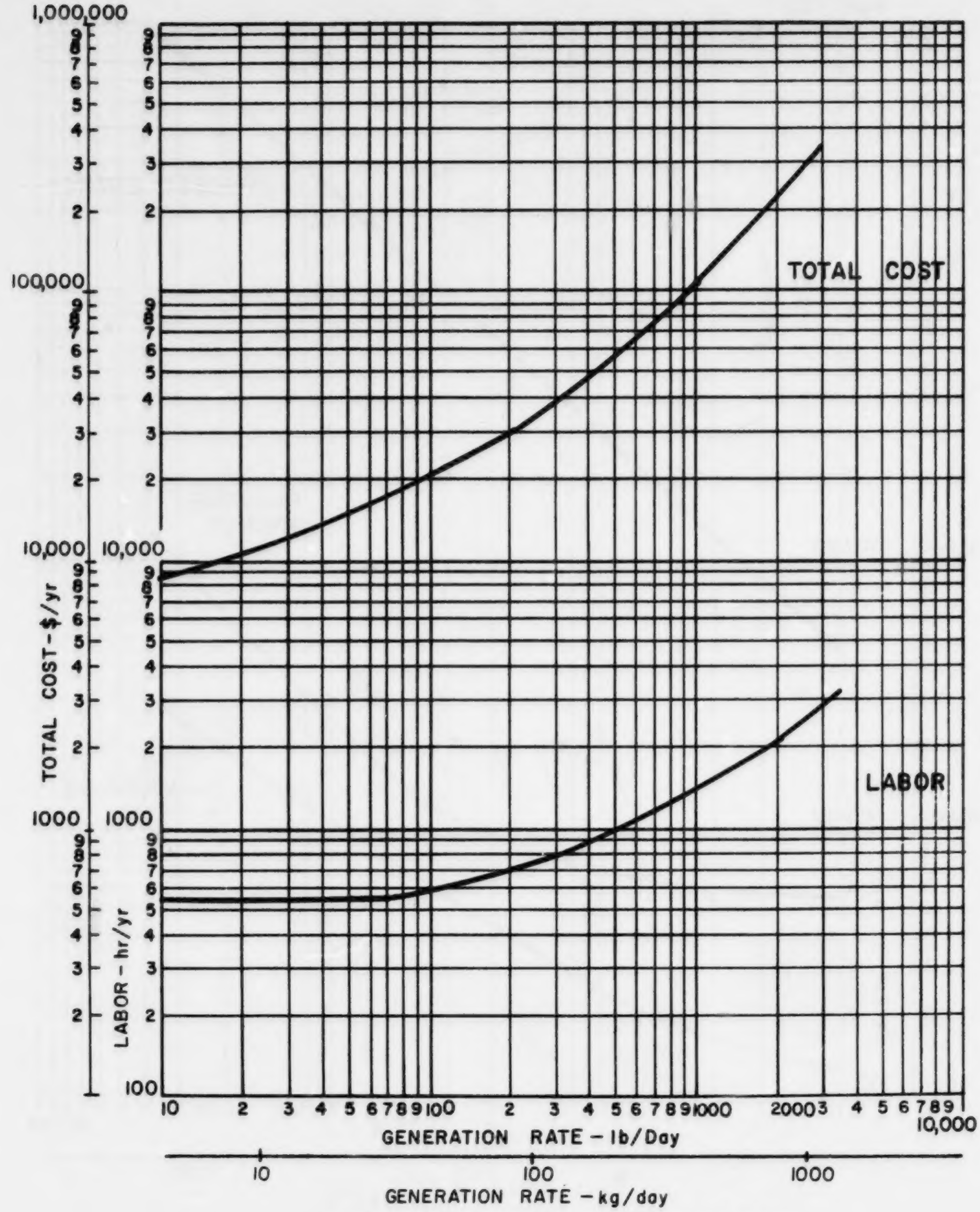
| Ozone Generation Rate - lb/day | Electrical Energy - kw-hr/yr Building | Electrical Energy - kw-hr/yr Process | Electrical Energy - kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 10 | 5,750 | 40,150 | 45,900 | 1,340 | 550 | 8,230 |
| 100 | 9,850 | 401,500 | 411,350 | 2,860 | 550 | 20,700 |
| 500 | 16,420 | 1,368,750 | 1,385,170 | 10,070 | 910 | 60,730 |
| 1,000 | 30,780 | 2,737,500 | 2,768,280 | 13,350 | 1,830 | 114,700 |
| 2,000 | 71,820 | 5,475,000 | 5,546,820 | 20,690 | 2,190 | 208,990 |
| 3,500 | 123,120 | 9,581,250 | 9,704,370 | 29,140 | 2,920 | 349,470 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
OZONE GENERATION SYSTEMS

FIGURE 35



OPERATION AND MAINTENANCE
OZONE GENERATION SYSTEMS

FIGURE 36

## CONSTRUCTION COST

### On-Site Hypochlorite Generation

Sodium hypochlorite may be produced in an electrolysis cell using salt, water and electrical energy. There are presently available two basic types of equipment which generate sodium hypochlorite solution. Open-cell systems have an electrolysis cell which includes an anode and cathode, with the actual cell arrangement varying between manufacturers. Membrane-type systems utilize a cell which has a membrane separating the anode and cathode compartments. A principal difference between the open-cell and membrane systems is the final sodium hypochlorite concentration. Manufacturers report a hypochlorite concentration of about 80,000 mg/l for the membrane cell and only about 5,000 to 8,000 mg/l for the other electrolysis cells. This has a pronounced effect on the required size of the hypochlorite storage facilities and feed systems.

A construction cost curve is shown in Figure 37 for systems with chlorine producing capacities ranging from 10 to 10,000 pounds per day of chlorine equivalent (Note: One pound of $Cl_2$ is equivalent to 1.05 pounds of sodium hypochlorite). For systems with a chlorine producing capacity of up to 2,500 pounds per day, the equipment utilized in the cost curve was based upon the open-cell systems. For systems from 2,500 to 10,000 pounds per day of chlorine, membrane-type systems were utilized due to their lower cost.

Components included in the construction cost estimate include the electrolysis cells, power rectifier, salt storage tank and brine dissolver, brine storage tank, water softener, brine transfer and metering pumps, hypochlorite transfer and metering pumps, hypochlorite storage tank, piping and valves, flowmeters, electrical control equipment and housing. It was assumed that the hypochlorite is pumped by a metering pump to a location for in-line mixing. The salt storage tank and brine dissolver was assumed to be located outside of the housing for systems with chlorine producing capacities of 500 pounds per day and larger.

A water softener is normally utilized as cleaning requirements are minimized when the total hardness of the water used for brine make-up is less than 30 mg/l. Use of purified salt is essential, either purchased or purified on-site. Small systems generally use purchased purified salt, but for systems with a chlorine producing capacity of greater than 2,000 pounds per day, it becomes economical to use a brine purification system and less expensive rock salt. A brine purification system is included in the cost estimate for systems larger than 2,000 pounds per day. The salt storage tank and brine dissolver is assumed to have a storage capacity of one month, while the sodium hypochlorite storage tank has a hypochlorite storage of 24 hours.

A relatively rapid increase in the cost of hypochlorite generating equipment occurs as the chlorine producing capacity increases from about 100 to 500 pounds per day. This increase occurs because systems of 100 pounds per day and smaller capacity are pre-designed and purchased as prefabricated units, whereas most systems of 500 pounds per day and larger capacity are custom-designed for the particular installation.

A detailed cost breakdown for generation systems is presented in Table 40 and a construction cost curve is shown in Figure 37.

## OPERATION AND MAINTENANCE COST

### On-Site Hypochlorite Generation

Operation and maintenance costs have been developed from information provided by manufacturers of on-site hypochlorite generation systems and also from operation and maintenance cost guarantees contained in several competitive bids. Operation and maintenance requirements are summarized in Table 41 and illustrated in Figures 38 and 39.

Energy requirements vary from about 2.0 to 4.7 kilowatt-hours per pound of chlorine equivalent, with the lowest energy consumption by the membrane-type cell. Energy requirements were developed using an electrolysis cell and rectifier usage of 2.5 kwh per pound of equivalent chlorine. Energy is also required for the electrical control system, the brine transfer and metering pumps, and the sodium hypochlorite transfer and metering pumps and is included under process energy. Electrical energy for lighting, heating, and ventilating is included under building energy.

The largest maintenance material requirement is for electrode replating or replacement. For estimating purposes, it was assumed that the electrodes were replated, or recoated, every two years. For the electrolysis cell utilizing a membrane, the entire electrolysis cell, including the anode, cathode, membrane, and cell frame, were assumed to be replaced every three years. Other maintenance material requirements are for cell gaskets for the membrane cell, for other miscellaneous parts associated with the electrolysis cells, and for materials needed for periodic repair of pumps, motors, and electrical control equipment. Salt requirements of the different manufactured equipment vary considerably. The reported salt requirements vary from about 2.0 to 4.5 pounds of salt per pound of chlorine equivalent, with the lowest salt consumption by the membrane-type system. Cost of salt is not included in the cost curves.

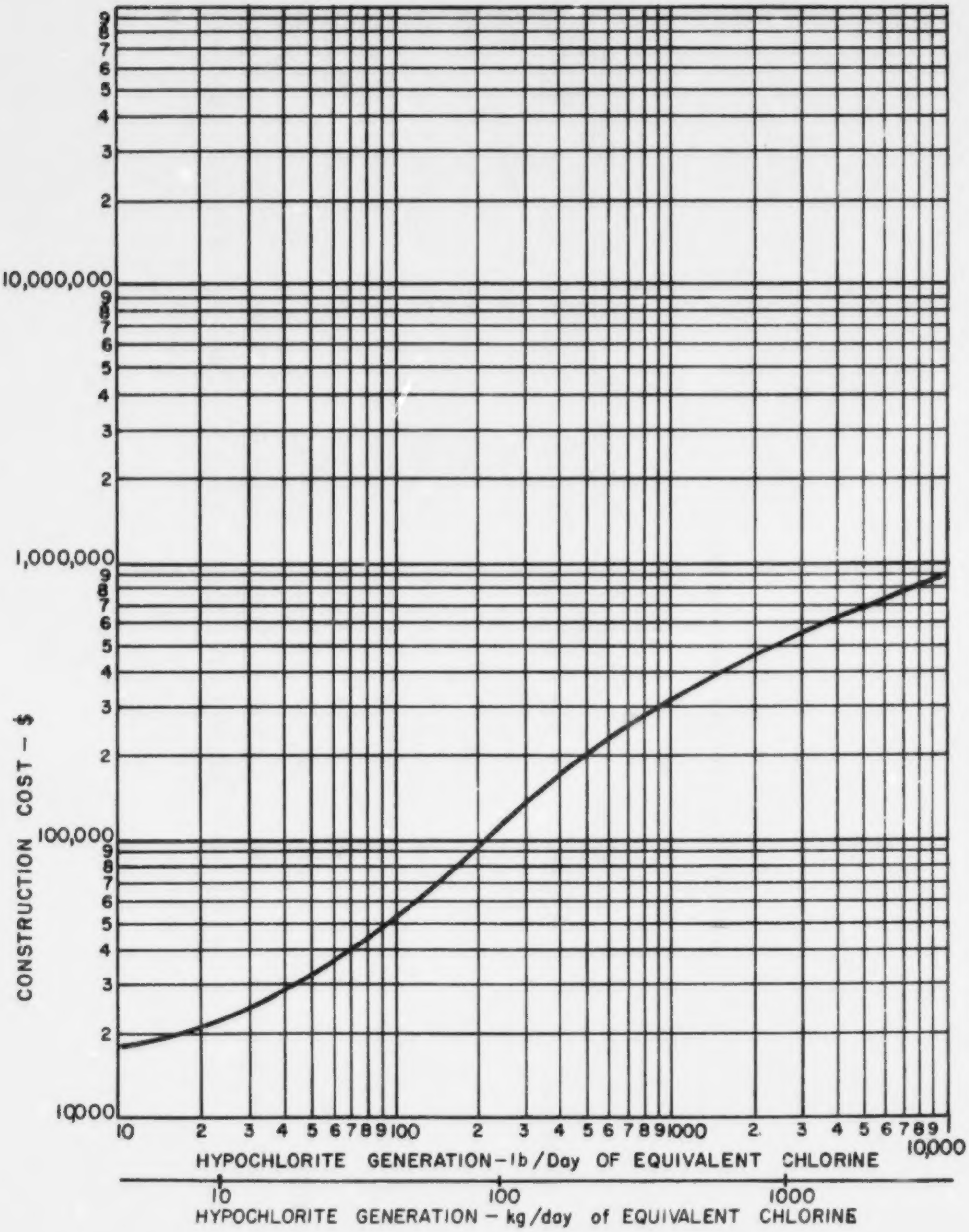
Labor requirements are for salt delivery and handling, operation of electrolysis cells, operation and maintenance of pumps, electrode replating or replacing, occasional cleaning of electrolysis cells, and for supplying and mixing brine purification chemicals for the larger systems. Labor requirements range from nearly one hour per day for the smallest system up to about 11 hours per day for the 10,000 pound per day system. The reduction in the labor requirement for the range from 100 to 200 pounds per day of chlorine is attributable to a change in the method of salt delivery, from a more labor intensive use of salt in bags to bulk salt delivery by pneumatic truck. The increase in the range from 1,500 to 2,500 pounds per day is due to the added labor required for brine purification, which is included for systems with a chlorine producing capacity of greater than 2,000 pounds per day.

## Table 40

## Construction Cost

## On-Site Hypochlorite Generation

| | Hypochlorite Generation - Pounds/day of Equivalent Chlorine | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10 | 50 | 250 | 1,000 | 2,500 | 5,000 | 10,000 |
| Manufactured Equipment | $ 5,600 | 12,000 | 65,000 | 180,000 | 290,000 | 400,000 | 550,000 |
| Concrete | -- | -- | -- | 180 | 350 | 350 | 530 |
| Steel | -- | -- | -- | 240 | 480 | 480 | 720 |
| Labor | 3,000 | 5,000 | 23,000 | 59,000 | 93,000 | 120,000 | 165,000 |
| Electrical and Instrumentation | 1,000 | 2,350 | 3,580 | 14,000 | 20,000 | 33,000 | 33,000 |
| Housing | 6,210 | 7,160 | 10,380 | 19,280 | 22,060 | 30,540 | 34,380 |
| SUBTOTAL | 15,810 | 26,510 | 101,960 | 272,700 | 425,890 | 584,370 | 788,630 |
| Miscellaneous and Contingency | 2,370 | 3,980 | 15,290 | 40,910 | 63,880 | 87,660 | 118,290 |
| TOTAL | $ 18,180 | 30,490 | 117,250 | 313,610 | 489,770 | 672,030 | 906,920 |



CONSTRUCTION COST
ON-SITE HYPOCHLORITE GENERATION

FIGURE 37

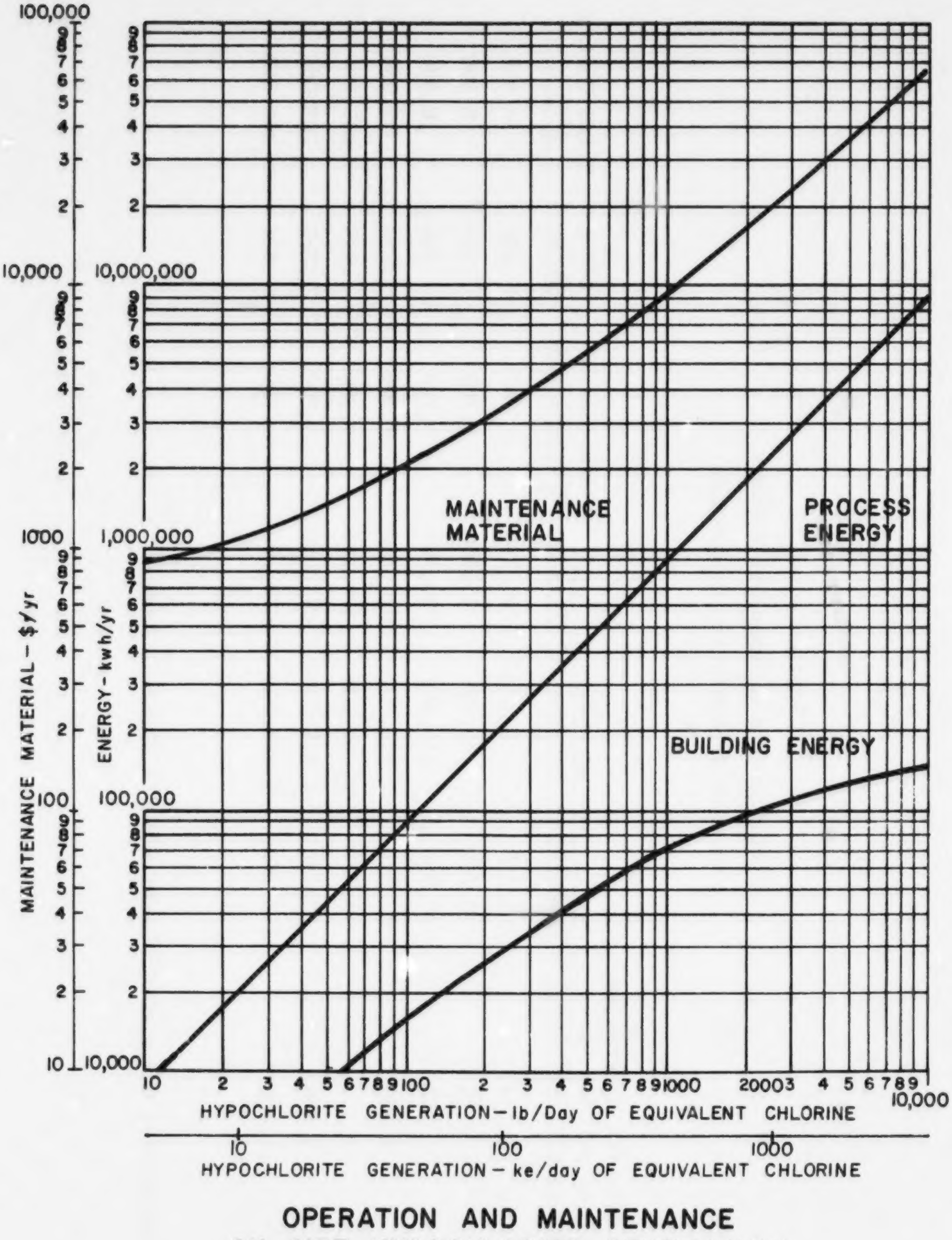
## Table 41

## Operation and Maintenance Summary

## On-Site Hypochlorite Generation

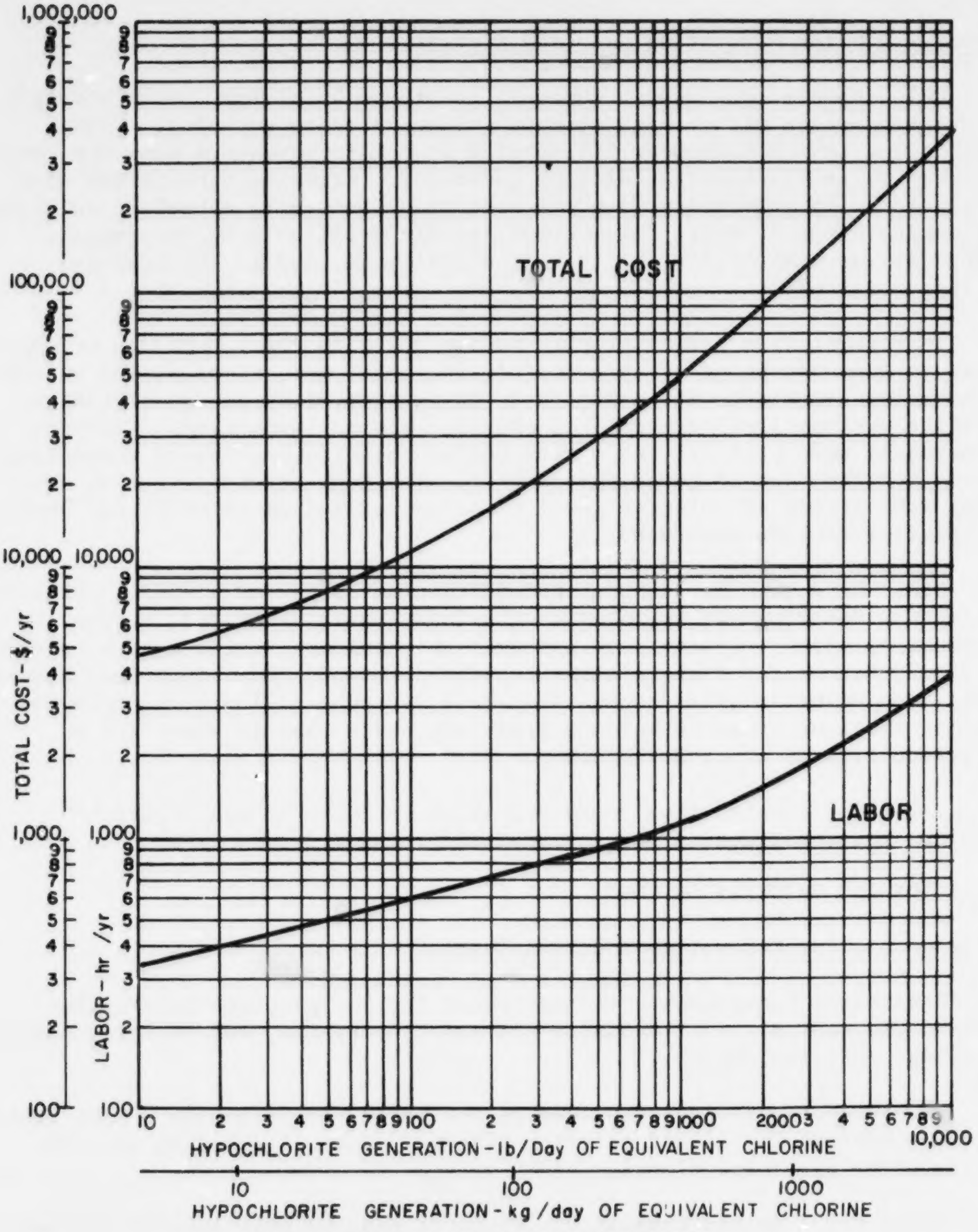
| Hypochlorite Generation Pounds per day of Equivalent Chlorine | Energy kwh/yr |  |  | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
|  | Building | Process | Total |  |  |  |
| 10 | 5,130 | 9,120 | 14,250 | 860 | 330 | 4,590 |
| 50 | 10,260 | 45,600 | 55,860 | 1,700 | 510 | 8,480 |
| 250 | 30,780 | 228,000 | 258,780 | 3,700 | 710 | 18,560 |
| 1,000 | 87,210 | 912,000 | 999,210 | 9,200 | 1,080 | 49,980 |
| 2,500 | 99,960 | 2,280,000 | 2,379,960 | 19,300 | 1,920 | 109,900 |
| 5,000 | 135,430 | 4,560,000 | 4,695,430 | 35,200 | 2,700 | 203,060 |
| 10,000 | 158,300 | 9,120,000 | 9,278,300 | 66,300 | 3,820 | 382,850 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
ON-SITE HYPOCHLORITE GENERATION

FIGURE 38



OPERATION AND MAINTENANCE
ON-SITE HYPOCHLORITE GENERATION

FIGURE 39

## CONSTRUCTION COST

### Chlorine Dioxide Generating and Feed Systems

Chlorine dioxide is most commonly generated by mixing a high strength chlorine solution with a high strenth sodium chlorite solution. Mixing takes place in a PVC chamber filled with procelain Raschig Rings, the chamber referred to as the chlorine dioxide generator. Chlorine dioxide may also be generated by acidifying with sulfuric acid, solutions of sodium chlorite and sodium hypochlorite. This method is only applicable in very small installations with little operator time available, and is not included in this cost curve

In theory, 1.34 pounds of pure sodium chlorite and 0.5 pounds of chlorine react to give one pound of chlorine dioxide. However, since sodium chlorite is normally purchased with a purity of 80 percent, 1.68 pounds of sodium chlorite are required per pound of chlorine dioxide generated. Chlorine is normally used at a 1:1 ratio with sodium chlorite, to insure completion of the reaction and to lower the pH to 4. The cost curves have been developed using 1.68 pounds of chlorine and 1.68 pounds of sodium chlorite per pound of chlorine dioxide generated.

Costs have been based upon the addition of costs for a sodium chlorite mixing and metering system, plus a chlorine dioxide generator, to the appropriate sized chlorine feed system. The sodium chlorite system consists of a polythelene day tank, a mixer for the day tank, and a dual head metering pump. The chlorine dioxide generator is a PVC tube filled with porcelain Raschig Rings or other turbulence producing media, and is sized for a detention time of about 0.2 minutes.

Estimated construction costs are shown in Table 42 and Figure 40 presents the construction costs graphically.

## OPERATION AND MAINTENANCE COST

### Chlorine Dioxide Generating and Feed Systems

Electrical requirements include power for the gaseous chlorination system, the sodium chlorite mixing and metering system, and building heating, lighting, and ventilation.

Maintenance material requirements are based upon experience with gaseous chlorine systems and liquid metering systems. Costs for sodium chlorite and chlorine are not included.

Labor requirements consist of labor for gaseous chlorination systems, plus the labor required to mix the sodium chlorite solution, to adjust its feed rate, and to maintain the mixing and metering equipment.

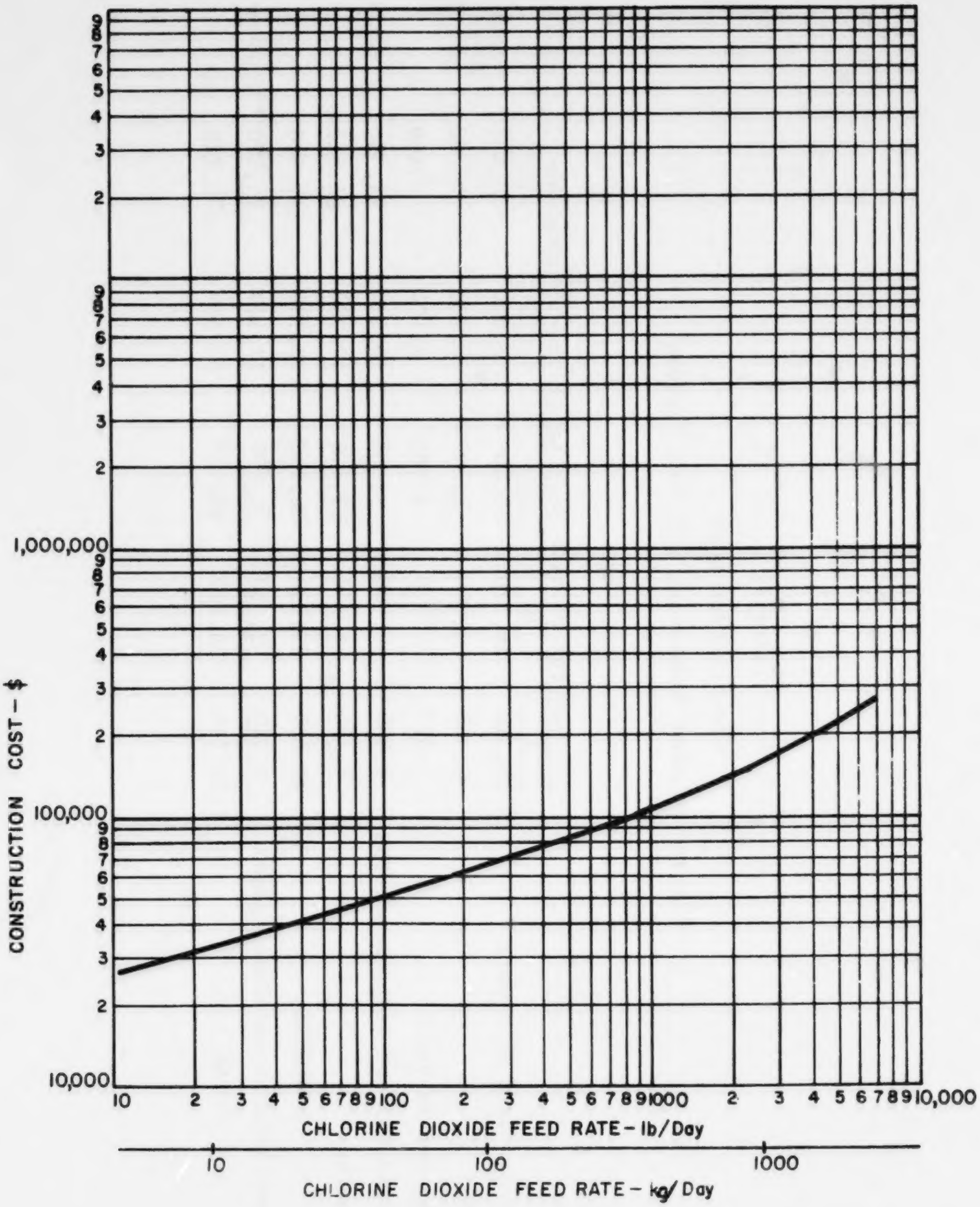
Figure 41 and 42 present operation and maintenance curves for chlorine dioxide generation systems. A summary of operation and maintenance requirements is presented in Table 43.

## Table 42

## Construction Cost

## Chlorine Dioxide Generating and Feed Systems

| | Chlorine Dioxide Feed Capacity - Pounds/day | | | | |
|---|---|---|---|---|---|
| | 1 | 10 | 100 | 1,000 | 5,000 |
| Manufactured Equipment | $ 10,310 | 10,310 | 20,000 | 35,690 | 78,690 |
| Labor | 1,300 | 1,300 | 2,500 | 10,730 | 32,780 |
| Pipe and Valves | 370 | 370 | 1,000 | 2,300 | 7,460 |
| Electrical and Instrumentation | 2,500 | 2,500 | 3,300 | 10,200 | 11,300 |
| Housing | 8,750 | 8,750 | 13,130 | 17,060 | 35,610 |
| SUBTOTAL | 23,230 | 23,230 | 39,930 | 75,980 | 165,840 |
| Miscellaneous and Contingency | 3,480 | 3,480 | 5,990 | 11,400 | 24,880 |
| TOTAL | $ 26,710 | 26,710 | 45,920 | 87,380 | 190,720 |



CONSTRUCTION COST
CHLORINE DIOXIDE GENERATING AND FEED SYSTEMS

FIGURE 40

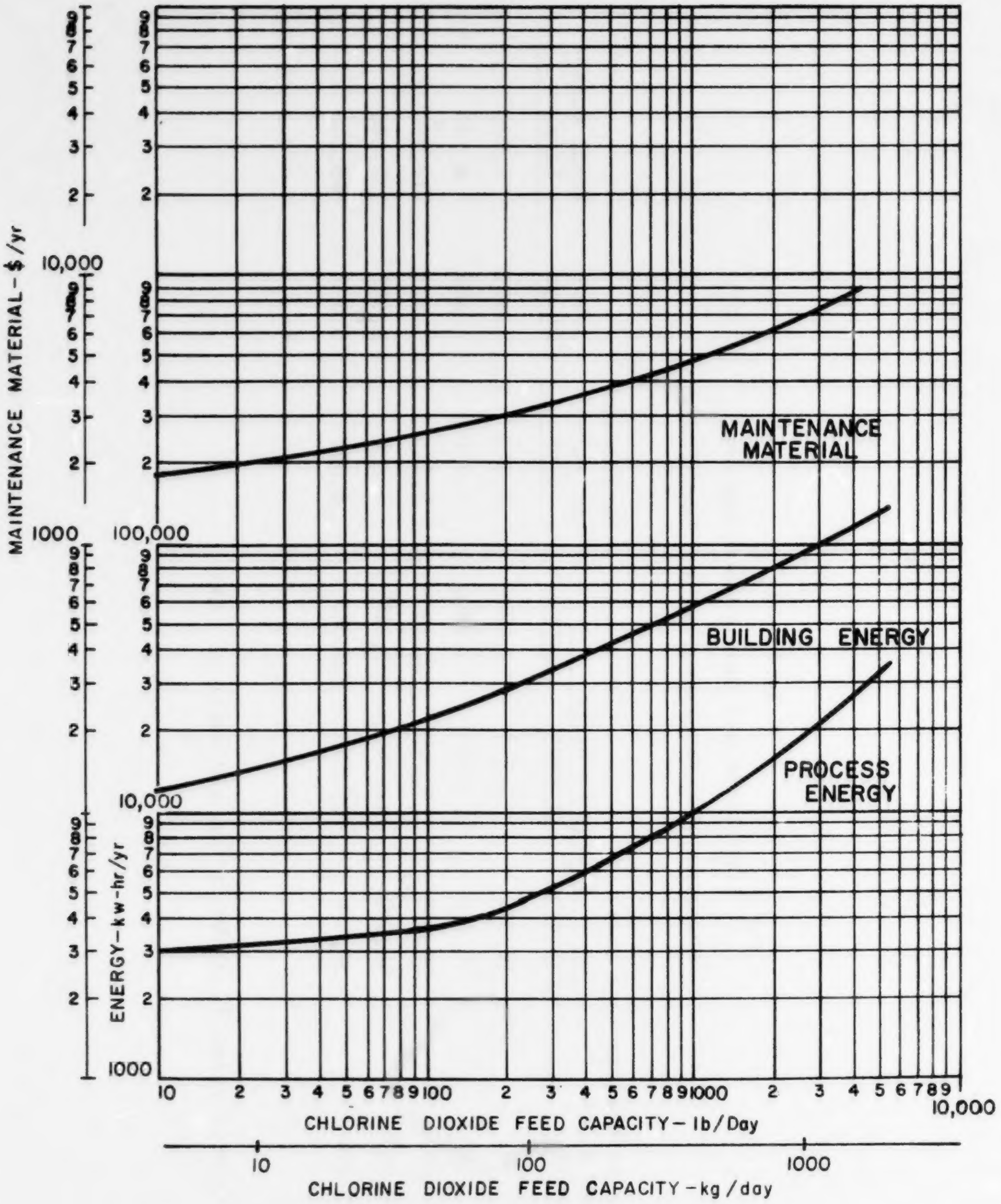
## Table 43

## Operation and Maintenance Summary

## Chlorine Dioxide Generating and Feed Systems

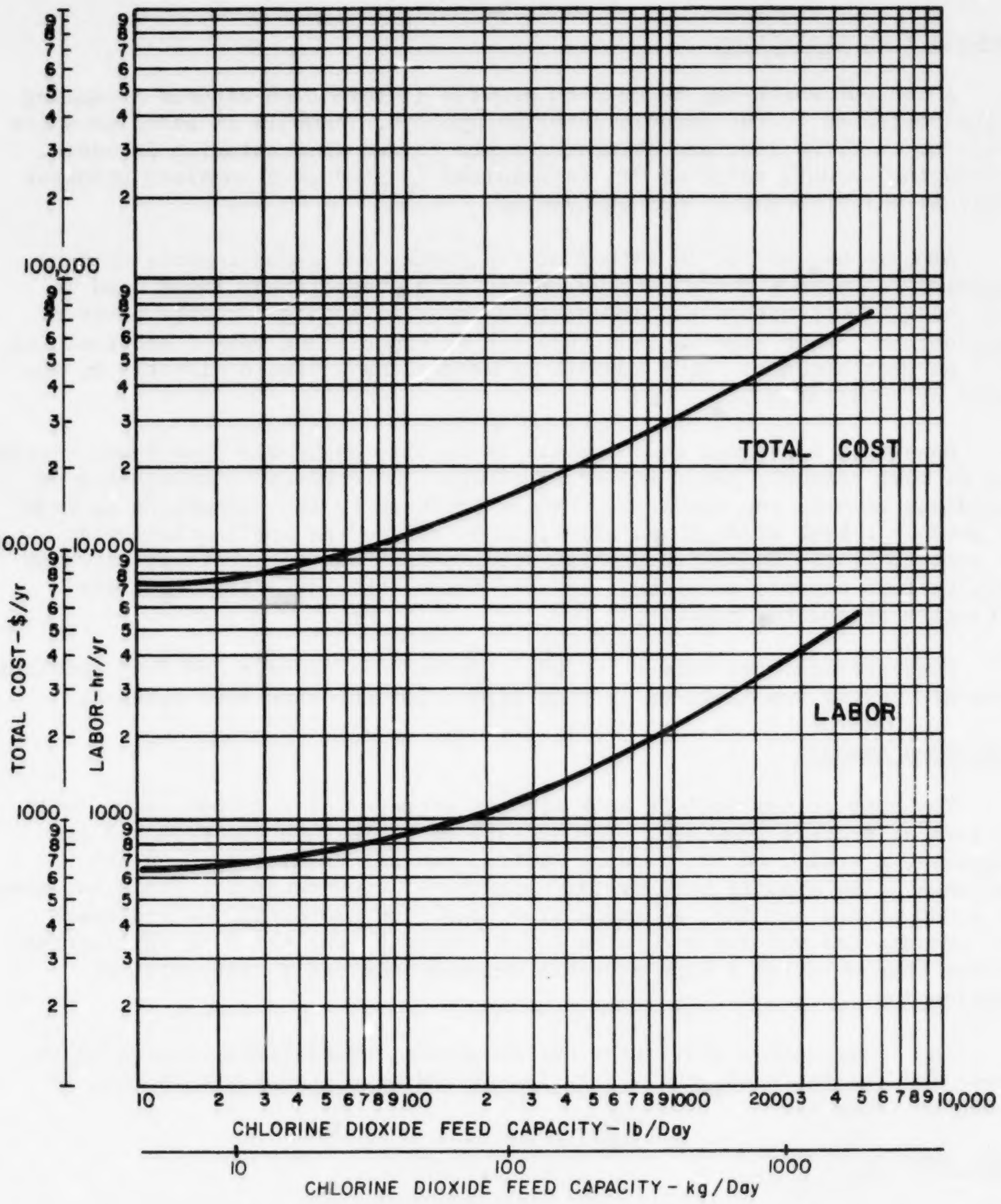
| Chlorine Dioxide Feed Rate lb/day | Energy kw-hr/yr | | | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| | Building | Process | Total | | | |
| 1 | 12,310 | 3,290 | 15,600 | 1,040 | 481 | 6,320 |
| 10 | 12,310 | 3,290 | 15,600 | 1,730 | 604 | 8,240 |
| 100 | 26,680 | 3,640 | 30,320 | 2,650 | 873 | 12,290 |
| 1,000 | 58,480 | 12,740 | 71,220 | 4,830 | 2,342 | 30,390 |
| 5,000 | 136,460 | 35,890 | 172,350 | 8,050 | 5,632 | 69,540 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
CHLORINE DIOXIDE GENERATING AND FEED SYSTEMS

FIGURE 41



OPERATION AND MAINTENANCE COST
CHLORINE DIOXIDE GENERATING AND FEED SYSTEMS

FIGURE 42

## CONSTRUCTION COST

### Ammonia Feed Facilities

A concept which may be used to provide disinfection without producing trihalomethanes is the ammonia-chlorine process. Ammonia is added to water prior to chlorination, and chloramines are formed when chlorine is added. A chlorine-ammonia ratio of 3:1 is required to produce a combined chlorine residual which is mainly monochloramine.

Ammonia may be fed in either of two forms, anhydrous ammonia or aqua ammonia. Anhydrous ammonia is purchased as a pressurized liquid, and is fed through evaporators and ammoniators and then as a gas to the point of application. Aqua ammonia is a solution of ammonia and water, and contains 29.4 percent ammonia. Aqua ammonia is metered as a liquid directly to the point of application.

Generally speaking, aqua ammonia is readily available near large cities, and is most commonly found in larger plants. A technical disadvantage of anhydrous ammonia can result if the gas produced by the ammoniator is used to produce a high strength solution, to be fed to the application point. In certain cases, magnesium precipitation occurs due to pH elevation which results from ammonia solution. In some cases, this severely restricts effective ammoniator capacity.

Construction cost curves include only ammonia storage and feed facilities. Separate curves are included in this Report for chlorine feed systems.

### Anhydrous Ammonia

The cost curves include bulk ammonia storage for all feed rates, with 10 days of storage provided. The storage tanks include the tank and its supports, a scale, an air padding system, and all required gauges and switches. The ammonia feed system consists of evaporator for flows in excess of 2,000 pounds per day, an ammoniator, and flow proportioning equipment. Dry ammonia gas was assumed to be fed directly to the point of application, rather than metering a high strength ammonia solution to the point of application.

The construction cost curve for anhydrous ammonia feed facilities is presented in Figure 43, and a detailed breakdown of construction cost is shown in Table 44.

### Aqua Ammonia

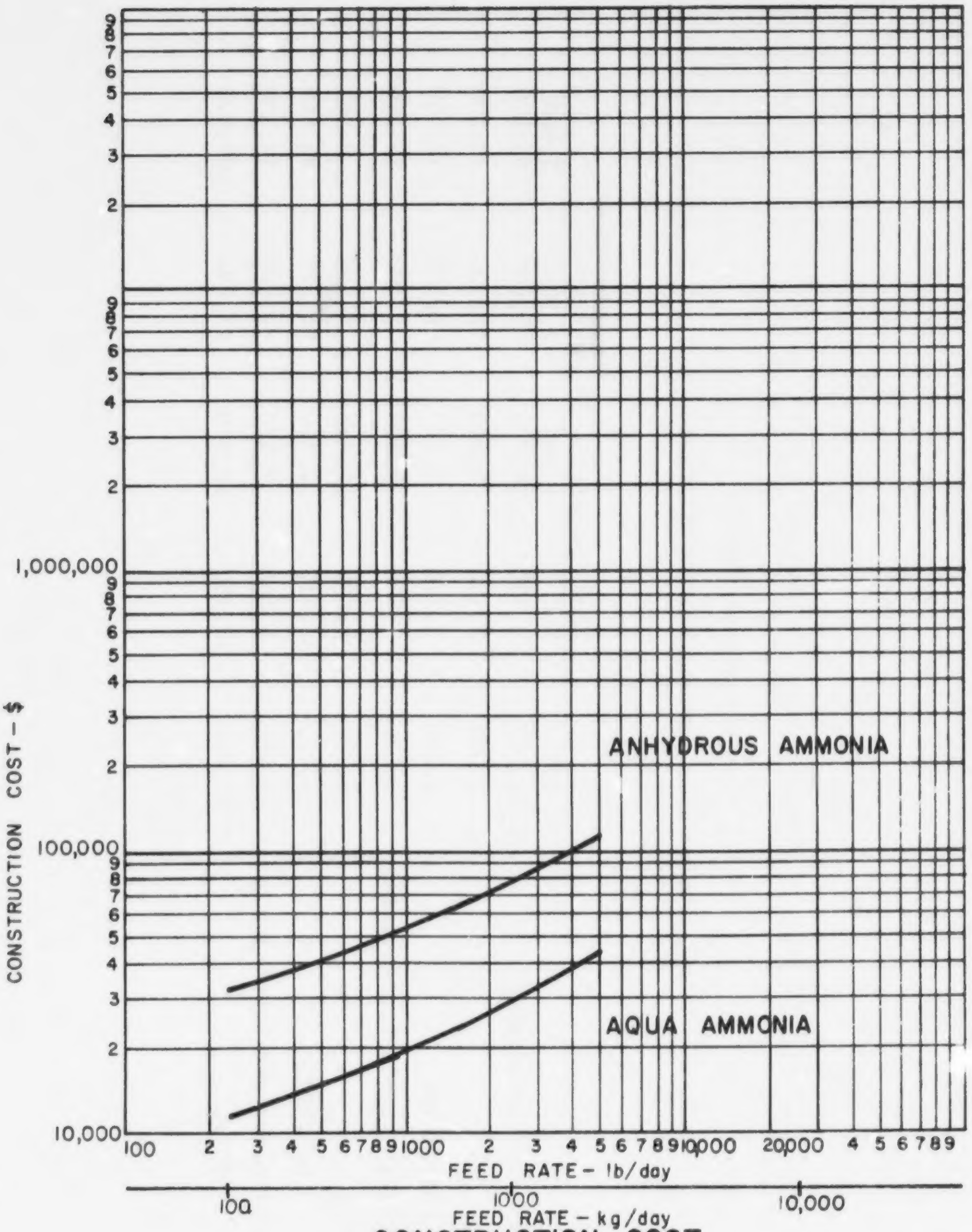
Aqua ammonia is stored in a horizontal pressure vessel with a length/width ratio of approximately 3:1. Only one tank was used for each installation and the assumed usable storage capacity was 10 days. Construction costs include the tank and its supports, required piping and valves for filling the tank from a bulk delivery truck and for conveying from the tank to the metering pump, and the metering pump. A housing cost is not included, because only the metering pump is housed, and it could easily be located in a number of other housed areas.

Table 44

Construction Cost

Anhydrous Ammonia Feed Facilities

| | Feed Capacity - Pounds/day | | | | |
|---|---|---|---|---|---|
| | 250 | 500 | 1,000 | 2,500 | 5,000 |
| Manufactured Equipment | $ 12,500 | 18,400 | 28,700 | 36,600 | 55,800 |
| Labor | 3,800 | 5,400 | 8,800 | 10,100 | 13,200 |
| Pipe and Valves | 2,250 | 3,310 | 5,170 | 6,590 | 10,040 |
| Electrical and Instrumentation | 3,100 | 3,600 | 5,900 | 8,100 | 10,500 |
| Housing | 4,200 | 4,200 | 4,200 | 4,200 | 6,000 |
| SUBTOTAL | 25,850 | 34,910 | 52,770 | 65,590 | 95,540 |
| Miscellaneous and Contingency | 3,880 | 5,240 | 7,920 | 9,840 | 14,330 |
| TOTAL | $ 29,730 | 40,150 | 60,690 | 75,430 | 109,870 |



CONSTRUCTION COST
AMMONIA FEED FACILITIES

FIGURE 43

The construction cost curve for aqua ammonia feed systems is presented in Figure 43 and a detailed breakdown is contained in Table 45.

## OPERATION AND MAINTENANCE COST

### Anhydrous Ammonia Feed Facilities

Electrical energy requirements are for heating, lighting, and ventilating of the ammoniator building, and operation of the evaporators. Evaporators are only included for systems of 2,000 pounds per day or greater, and evaporator energy requirements were calculated on the basis of 23.8 kw-hr/ton of ammonia.

Maintenance material requirements were based upon operating experience at similar size chlorination facilities. Anhydrous ammonia costs are not included in the maintenance material costs.

Labor requirements are for transfer of the bulk anhydrous ammonia from the delivery truck or rail car to the on-site ammonia storage tank, plus day to day operation and maintenance requirements. A bulk unloading time of 3 hours per shipment was utilized. Operation and maintenance requirements varied from roughly one and a half hours per day for the smaller systems to three hours per day for larger systems.

Figures 44 and 45 present the operation and maintenance curves, and Table 46 presents a summary of the operation and maintenance requirements.

### Aqua Ammonia Feed Facilities

Electrical energy costs are only for operation of the metering pump. Due to the small indoor area required for the metering pump and standby pump no allowance is included for building heating, lighting, and ventilation. Transfer of aqua ammonia from the bulk truck to the storage tank was assumed to be by a pump located on the bulk truck.

Maintenance material costs are for repair parts for the metering pump, valve repair, and painting of the storage tank. Aqua ammonia costs are not included in the maintenance material costs.

Labor costs include 15 minutes per day for operational labor, 24 hours per year for maintenance labor, and one hour per unloading of the bulk delivery truck.

Operation and maintenance requirements are presented in Figures 46 and 47 and summarized in Table 47.

## Table 45

## Construction Cost

## Aqua Ammonia Feed Facilities

| | Feed Capacity - Pounds/day | | | | |
|---|---|---|---|---|---|
| | 250 | 500 | 1,000 | 2,500 | 5,000 |
| Manufactured Equipment | $ 7,630 | 9,830 | 12,710 | 18,230 | 26,710 |
| Labor | 960 | 970 | 1,130 | 1,220 | 1,360 |
| Pipe and Valves | 630 | 630 | 860 | 1,590 | 1,590 |
| Electrical and Instrumentation | 1,000 | 2,400 | 2,800 | 5,000 | 7,200 |
| SUBTOTAL | 10,220 | 13,830 | 17,500 | 26,040 | 36,860 |
| Miscellaneous and Contingency | 1,530 | 2,070 | 2,630 | 3,910 | 5,530 |
| TOTAL | $ 11,750 | 15,900 | 20,130 | 29,950 | 42,390 |

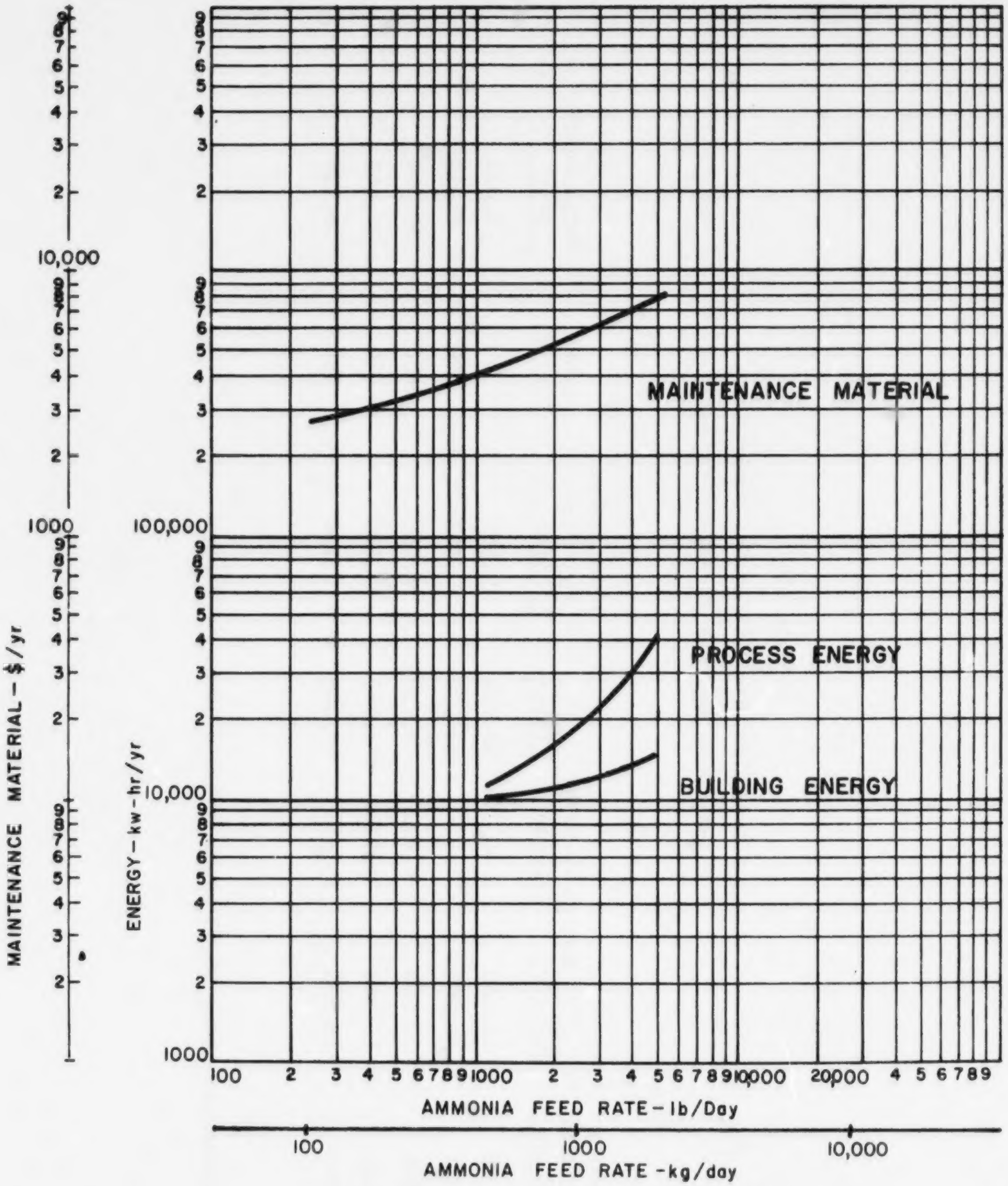
## Table 46

## Operation and Maintenance Summary

## Anhydrous Ammonia Feed Facilities

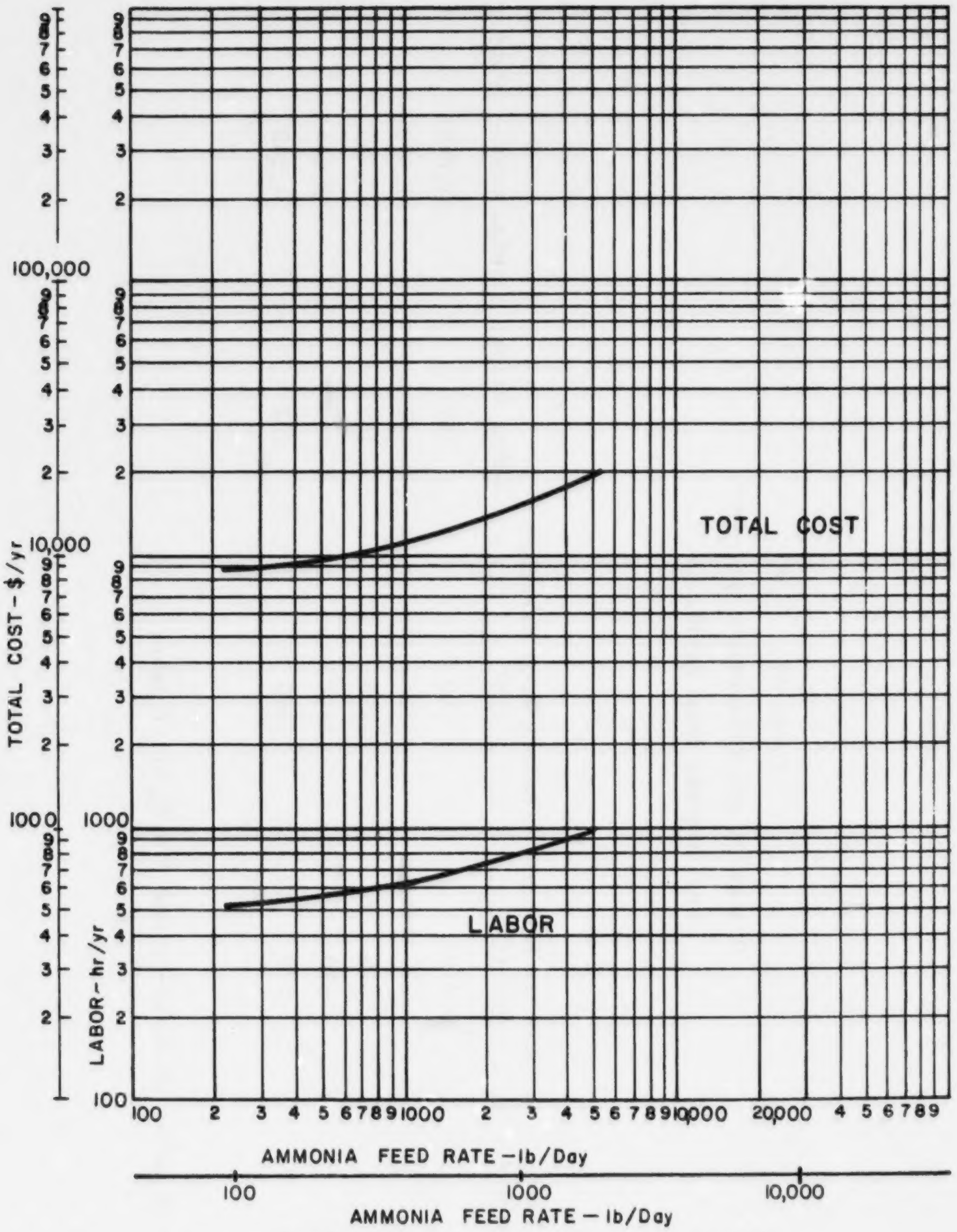
| Ammonia Feed Rate lb/day | Energy kw-hr/yr |  |  | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
|  | Building | Process | Total |  |  |  |
| 250 | 10,260 | -- | 10,260 | 2,860 | 500 | 8,070 |
| 500 | 10,260 | -- | 10,260 | 3,300 | 580 | 9,310 |
| 1,000 | 10,260 | 8,690 | 18,950 | 4,400 | 630 | 11,170 |
| 2,500 | 10,260 | 21,720 | 31,980 | 5,500 | 780 | 14,160 |
| 5,000 | 15,390 | 43,450 | 58,840 | 7,700 | 990 | 19,220 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
ANHYDROUS AMMONIA FEED FACILITIES

FIGURE 44



OPERATION AND MAINTENANCE
ANHYDROUS AMMONIA FEED FACILITIES

FIGURE 45

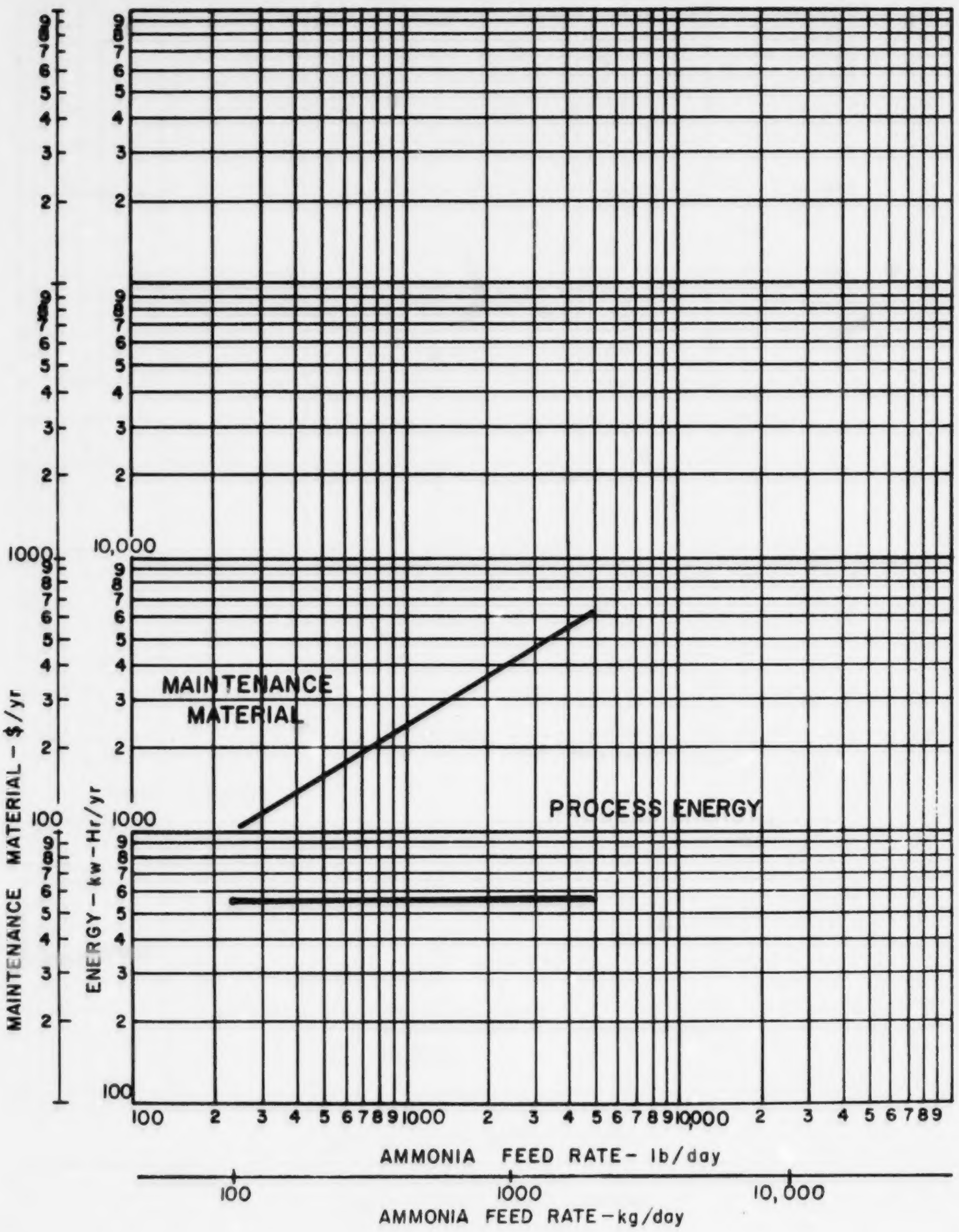
## Table 47

## Operation and Maintenance Summary

## Aqua Ammonia Feed Facilities

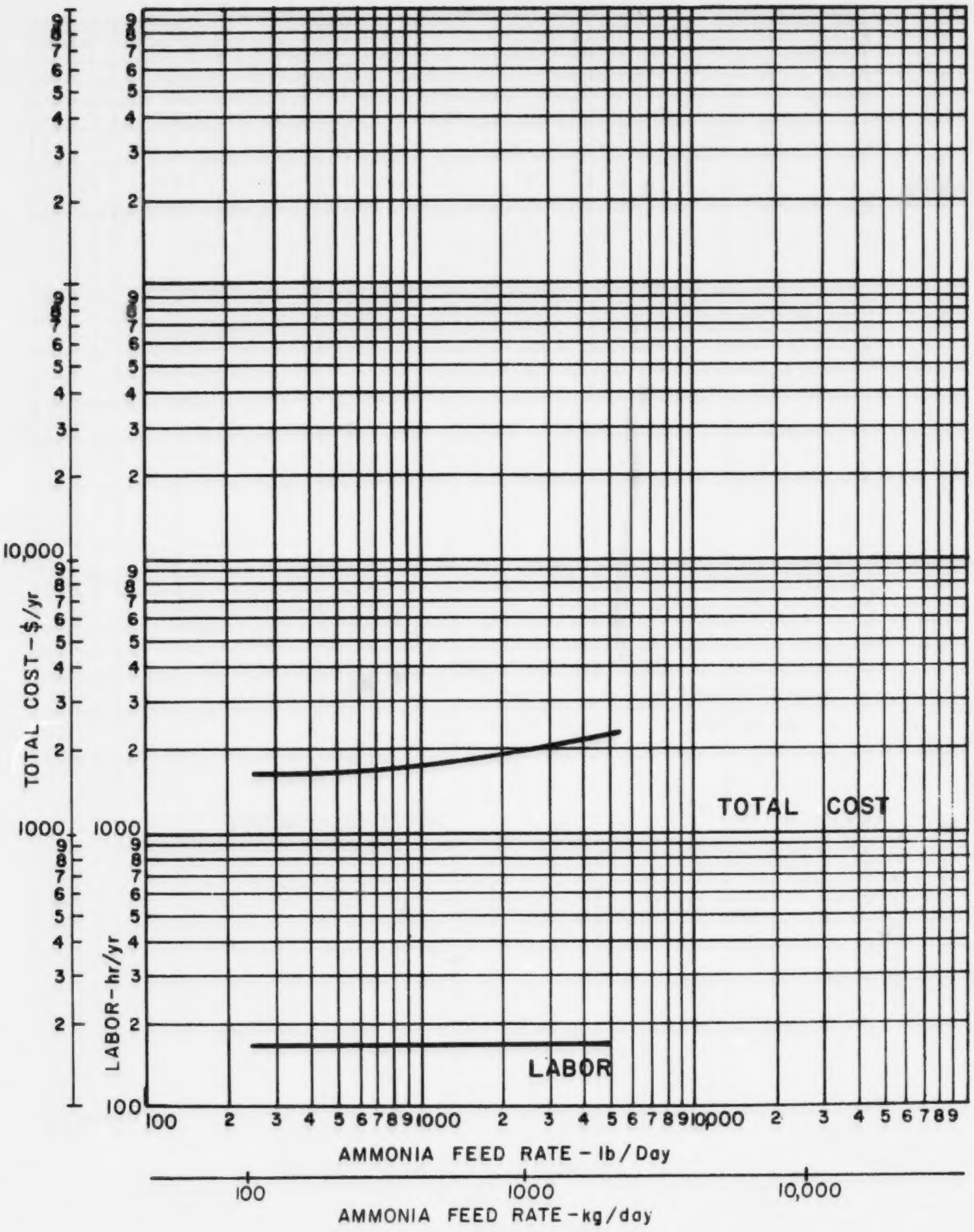
| Ammonia Feed Rate - lb/day | Process Energy kw-hr/yr | Maintenance Material $/yr | Labor hr/yr | Total Cost - $/yr* |
|---|---|---|---|---|
| 250 | 570 | 100 | 152 | 1,640 |
| 500 | 570 | 150 | 152 | 1,690 |
| 1,000 | 570 | 250 | 152 | 1,790 |
| 2,500 | 570 | 400 | 152 | 1,940 |
| 5,000 | 570 | 600 | 152 | 2,140 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
AQUA AMMONIA FEED FACILITIES

FIGURE 46



OPERATION AND MAINTENANCE
AQUA AMMONIA FEED FACILITIES

FIGURE 47

## CONSTRUCTION COSTS

### Alum Feed Systems

#### Liquid Alum

Cost estimated for liquid alum feed systems are based upon use of liquid alum, which has a weight of 10 pounds per gallon and contains the equivalent of 5 pounds of commercial dry alum per gallon. Fifteen days of storage are provided using fiberglas reinforced polyester (FRP) tanks. The FRP tanks were assumed to be uncovered and located indoors for smaller installations, and outdoors for larger installations. Outdoor tanks are covered and vented, with insulation and heating provided to prevent crystallization, which occurs at temperatures below 30°F.

Dual head metering pumps were used to pump liquid alum from the storage tank and meter the flow directly to the point of application. No provision was made for dilution of the liquid alum prior to application. A standby metering pump was included for each installation. All pipe utilized to convey the liquid alum was 316 stainless steel, and 150 feet of pipe, along with miscellaneous fittings and valves were included for each metering pump.

Construction costs for liquid alum feed are presented in Table 48 and shown graphically on Figure 48.

#### Dry Alum

Cost estimates for solid alum feed facilities are based upon use of commercial dry alum with a density of 60 pounds per cubic foot. A five minute detention period is required in the dissolving tank, and 2 gallons of water are used per pound of alum. Fifteen days of dry alum storage is included, using mild steel storage hoppers located indoors. Conveyance of alum from bulk delivery trucks to the hoppers is pneumatically with the blower located on the delivery truck. The largest hopper capacity utilized was 6,000 cubic feet. For installations too small for bulk delivery, bag loaders are used on the feeder. All hopper facilities included dust collectors.

Volumetric feeders for the smaller installations and mechanical weigh belt feeders for the large installations and their respective solution tanks were located directly beneath the storage hoppers, eliminating the need for bucket elevators or other conveyance devices from below ground storage. Such installation does, however, make the building cost somewhat greater than other possible arrangements. Conveyance from the solution tanks to the point of application was by dual head diaphram metering pumps.

Construction cost estimates for solid alum feed are presented in Table 49 and shown graphically in Figure 48.

## Table 48

## Construction Cost

## Liquid Alum Feed Systems

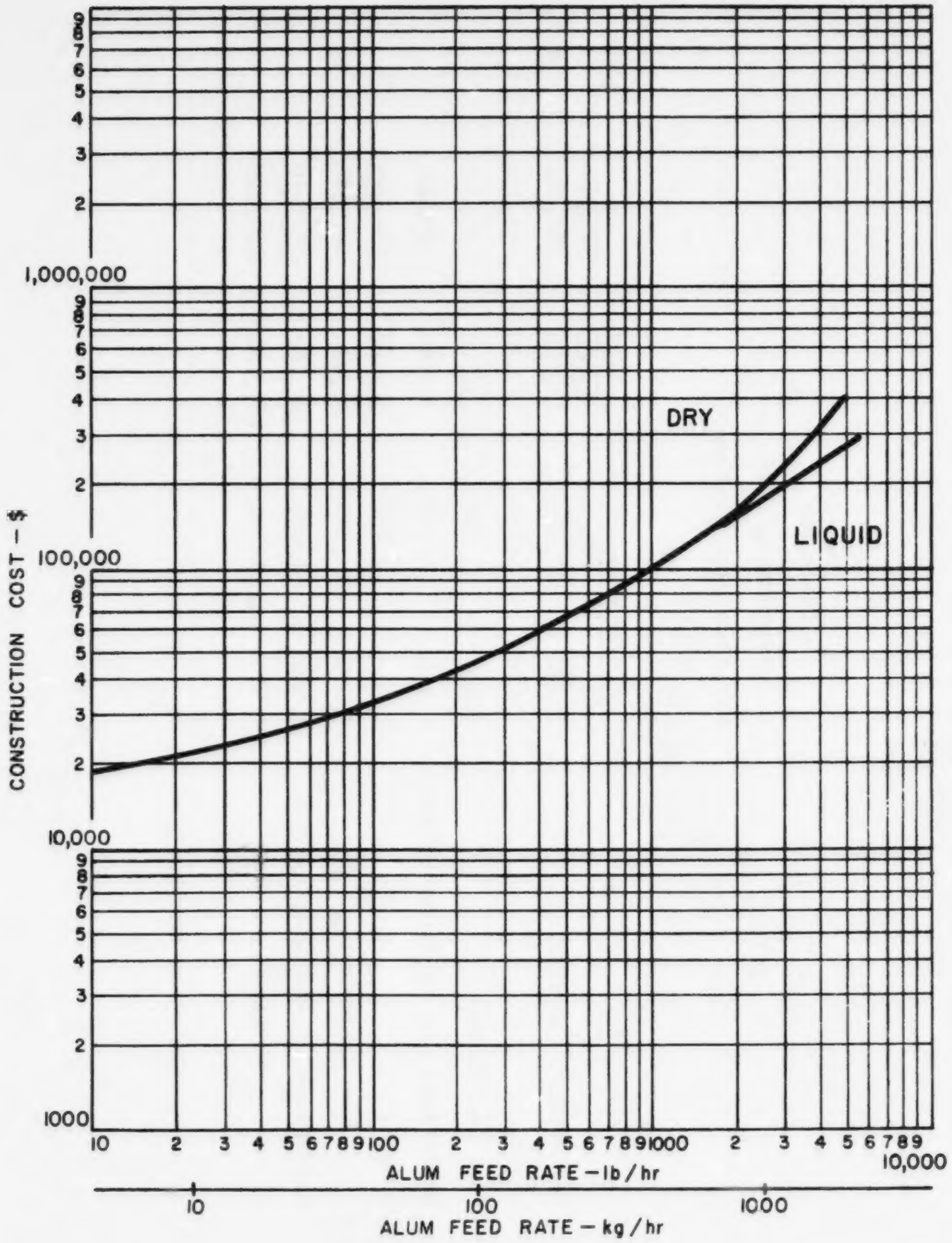
| | Feed Capacity - lb/hr | | | |
|---|---|---|---|---|
| | 5.4 | 54 | 540 | 5,400 |
| Manufactured Equipment | $ 4,200 | 5,480 | 23,950 | 188,730 |
| Labor | 950 | 1,170 | 4,220 | 34,570 |
| Pipe and Valves | 940 | 940 | 940 | 4,680 |
| Electrical and Instrumentation | 3,000 | 3,250 | 4,700 | 14,100 |
| Housing | 5,500 | 13,970 | 25,840 | 8,400 |
| SUBTOTAL | 14,590 | 24,810 | 59,650 | 250,480 |
| Miscellaneous and Contingency | 2,190 | 3,720 | 8,950 | 37,570 |
| TOTAL | $ 16,780 | 28,530 | 68,600 | 288,050 |

## Table 49

## Construction Cost

## Dry Alum Feed Systems

| | Feed Capacity - Pounds/hr | | | |
|---|---|---|---|---|
| | 10 | 100 | 1,000 | 5,000 |
| Manufactured Equipment | $ 7,500 | 13,100 | 33,560 | 160,940 |
| Labor | 420 | 1,130 | 2,430 | 12,160 |
| Pipe and Valves | 2,000 | 2,500 | 3,000 | 15,000 |
| Electrical and Instrumentation | 1,110 | 2,260 | 4,960 | 19,000 |
| Housing | 6,000 | 13,300 | 51,270 | 174,590 |
| SUBTOTAL | 17,030 | 32,290 | 95,220 | 381,690 |
| Miscellaneous and Contingency | 2,550 | 4,840 | 14,280 | 57,250 |
| TOTAL | $ 19,580 | 37,130 | 109,500 | 438,940 |



CONSTRUCTION COST
ALUM FEED SYSTEMS

FIGURE 48

## OPERATION AND MAINTENANCE COST

### Alum Feed Systems

Electrical requirements are for solution mixers, feeder operation, building lighting, ventilation, and heating and in the case of larger liquid feed installations, for heating of outdoor storage tanks. The sharp decrease in the building energy curve for high feed rates is attributable to the use of outdoor storage tanks, as contrasted to use of indoor storage tanks at lower flow rates.

Maintenance material costs were estimated on the basis of three percent of the manufactured equipment cost, excluding storage tank cost. Alum costs are not included in the maintenance material costs.

Labor requirements consist of time for chemical unloading and routine operation and maintenance of feeding equipment. Liquid alum unloading requirements were calculated on the basis of 1.5 hours per bulk truck delivery, and dry alum requirements on the basis of 5 hours per 50,000 pounds. For dry feed installations using alum from bags, 8 hours were used per 16,000 pounds removed and fed to the bag loader hopper. Time for routine inspection and adjustment of feeders is 10 minutes/feeder/shift for dry feed and 15 minutes/metering pump/shift for liquid feed. Maintenance requirements were 8 hours per day for liquid metering pumps and 24 hours per day for solid feeders and the solution tank.

Figures 49 to 52 present operation and maintenance costs for both liquid alum feed and dry alum feed. A summary of operation and maintenance requirements is presented in Table 50.

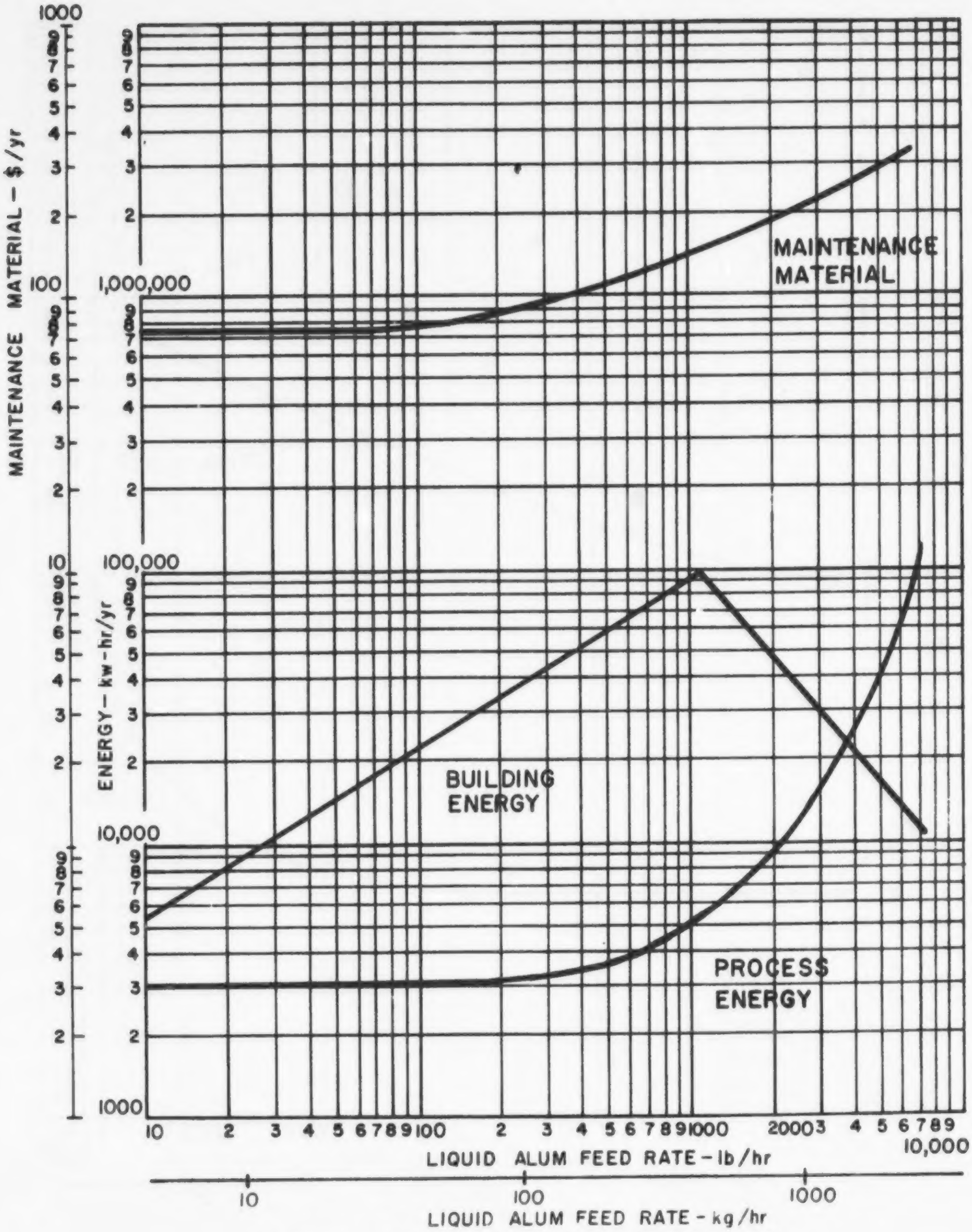
## Table 50

## Operation and Maintenance Summary

## Alum Feed Systems

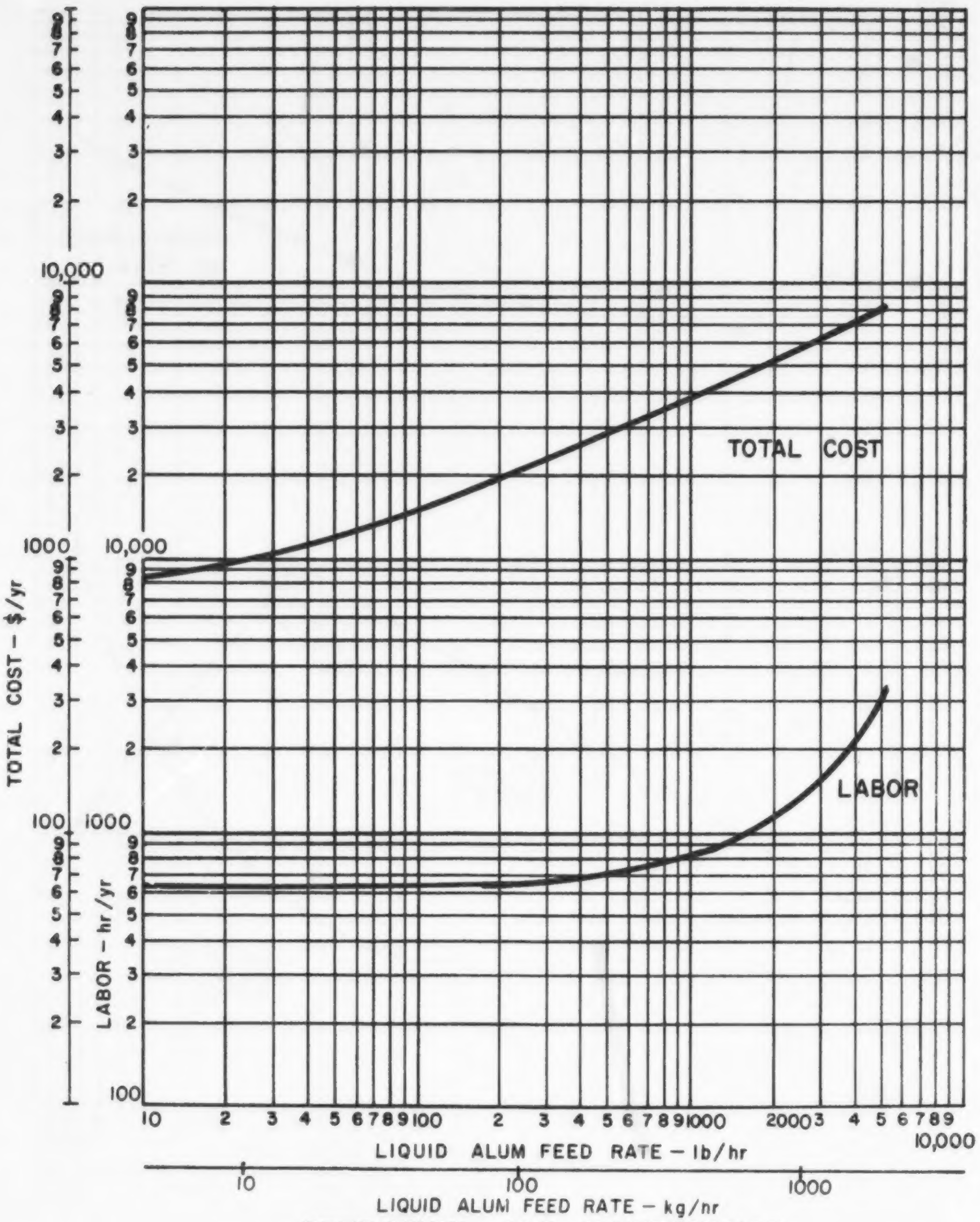
|  |  | Energy kw-hr/yr |  |  | Maintenance Material |  |  |
|---|---|---|---|---|---|---|---|
|  | Alum Feed Rate | Building | Process | Total | $/yr | Labor hr/yr | Total Cost* $/yr |
| Dry Alum | 10 lb/hr | 6,160 | 4,900 | 11,060 | 180 | 288 | 3,390 |
|  | 100 lb/hr | 23,090 | 4,900 | 27,990 | 210 | 332 | 4,370 |
|  | 1,000 lb/hr | 63,920 | 6,530 | 70,450 | 300 | 1,124 | 13,650 |
|  | 5,000 lb/hr | 320,630 | 9,800 | 330,430 | 1,330 | 4,624 | 57,480 |
| Liquid Alum | 5.4 lb/hr | 5,130 | 3,270 | 8,400 | 70 | 63 | 950 |
|  | 54 lb/hr | 24,210 | 3,270 | 27,480 | 70 | 63 | 1,520 |
|  | 540 lb/hr | 99,520 | 5,450 | 104,970 | 100 | 63 | 3,880 |
|  | 5,400 lb/hr | 10,260 | 116,340 | 126,600 | 330 | 315 | 7,280 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



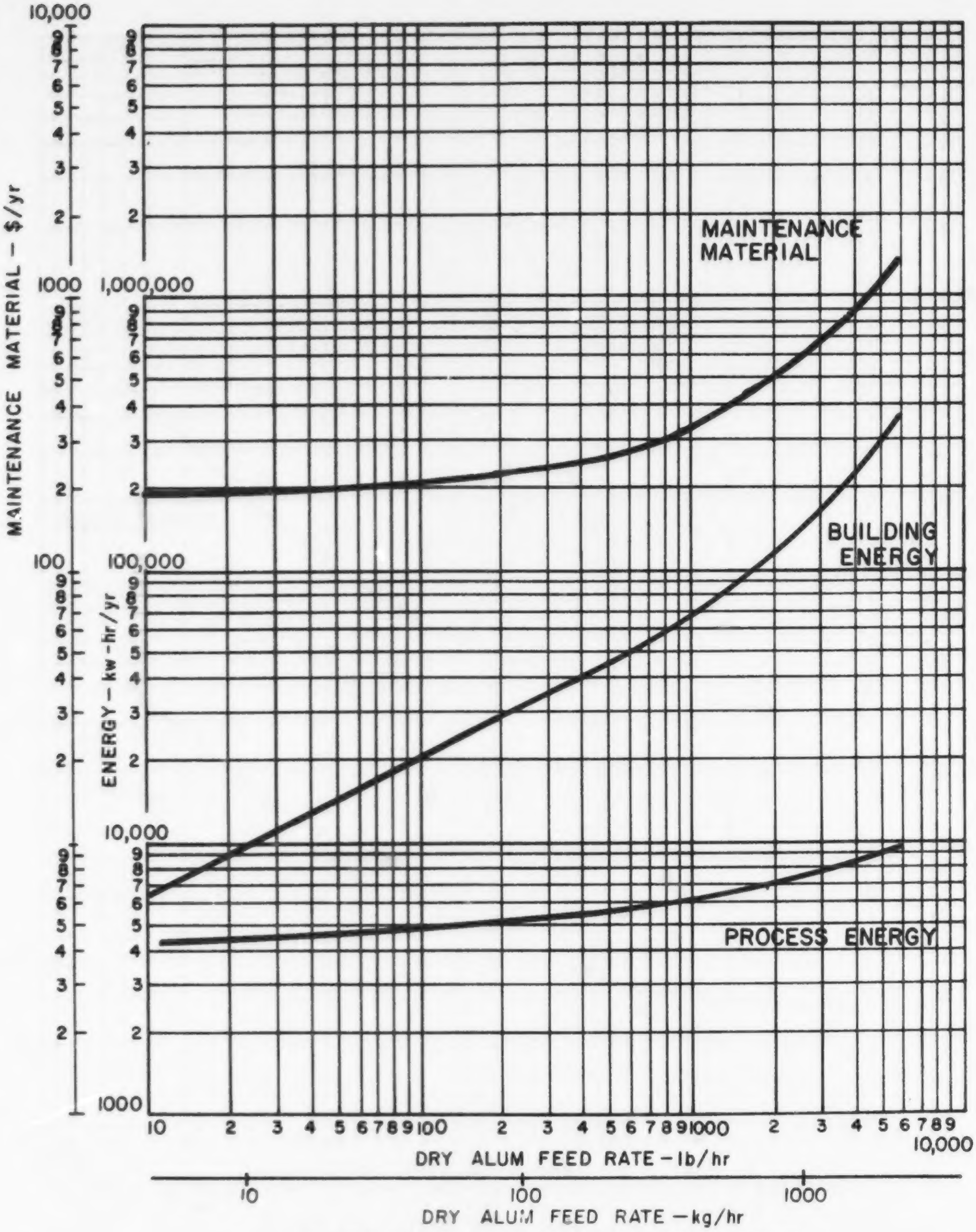
OPERATION AND MAINTENANCE
LIQUID ALUM FEED SYSTEMS

FIGURE 49



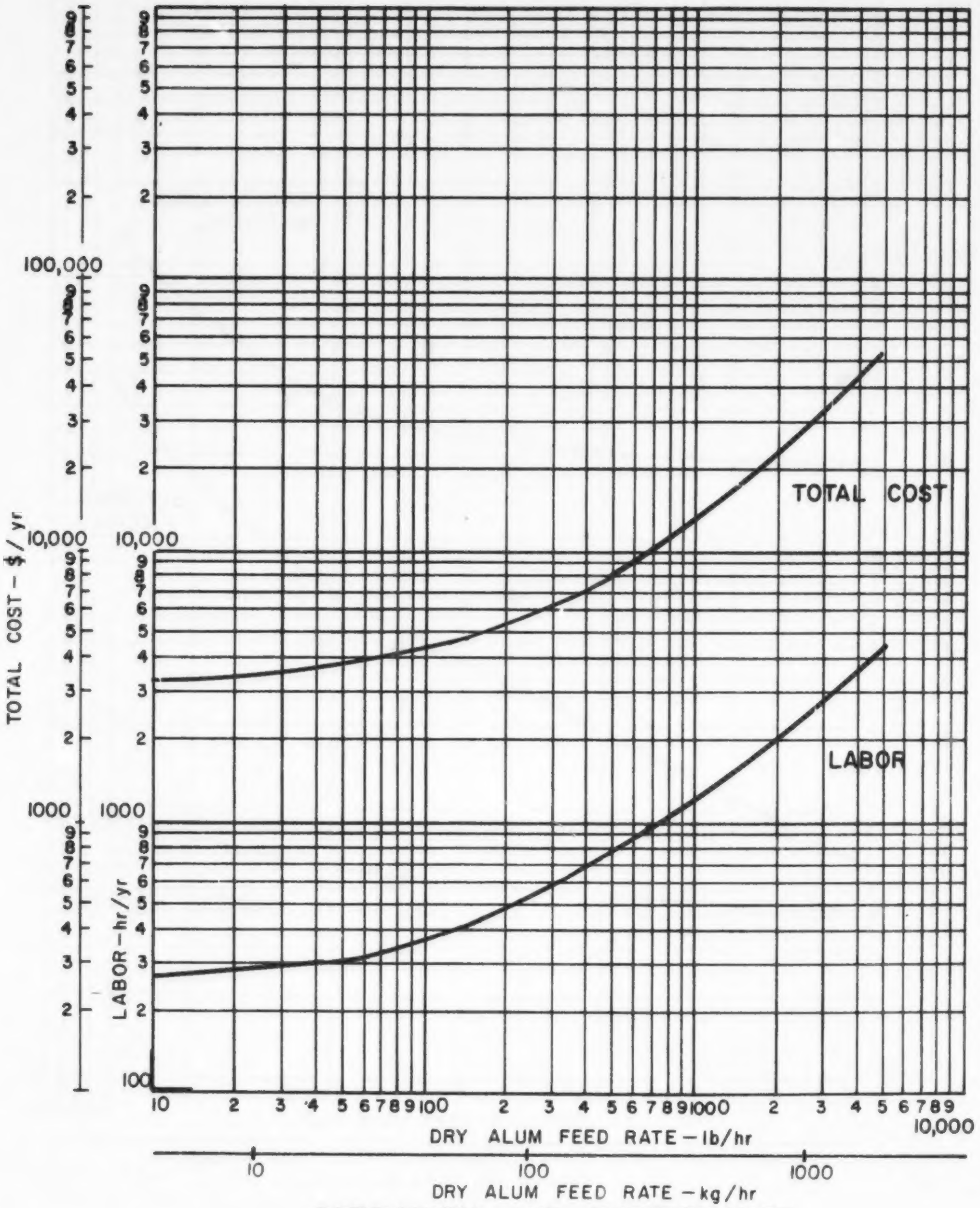
OPERATION AND MAINTENANCE
LIQUID ALUM FEED SYSTEMS

FIGURE 50



OPERATION AND MAINTENANCE
DRY ALUM FEED SYSTEMS

FIGURE 51



OPERATION AND MAINTENANCE
DRY ALUM FEED SYSTEMS

FIGURE 52

## CONSTRUCTION COST

### Polymer Feed Systems

Cost estimates for polymer feed systems are based upon the use of dry polymers, fed manually to a storage hopper located on the chemical feeder. Chemical feed equipment is based upon preparation of a 0.25 percent stock solution. No provision has been made for standby or redundant equipment, as polymer would generally be utilized only as a coagulant aid or a filter aid, and thus an equipment breakdown could be tolerated for a short period of time while equipment is repaired.

In addition to the manufactured feeder and solution tank, costs have also been included for the water piping to the feeder and a polymer solution line out of the building, installation labor, the cost of housing for the feeder/mixer, and a bag storage area for up to 15 days storage.

The estimated costs are presented on Table 51 and are shown graphically in Figure 53.

## OPERATION AND MAINTENANCE COST

### Polymer Feed Systems

Energy requirements for the feeder and metering pump were calculated using motor horsepower requirements recommended by manufacturers. Building energy requirements are based upon completely housed systems.

Maintenance material costs used are 3 percent of manufactured equipment and pipe/valve costs. These costs do not include the cost of polymer.

Labor requirements are for bag unloading, 1 hour per ton of bags, the dry chemical feeder, 110 hours/year for routine operation and 24 hours per year for maintenance, and the solution metering pump, 55 hours/year for routine operation and 8 hours per year for maintenance.

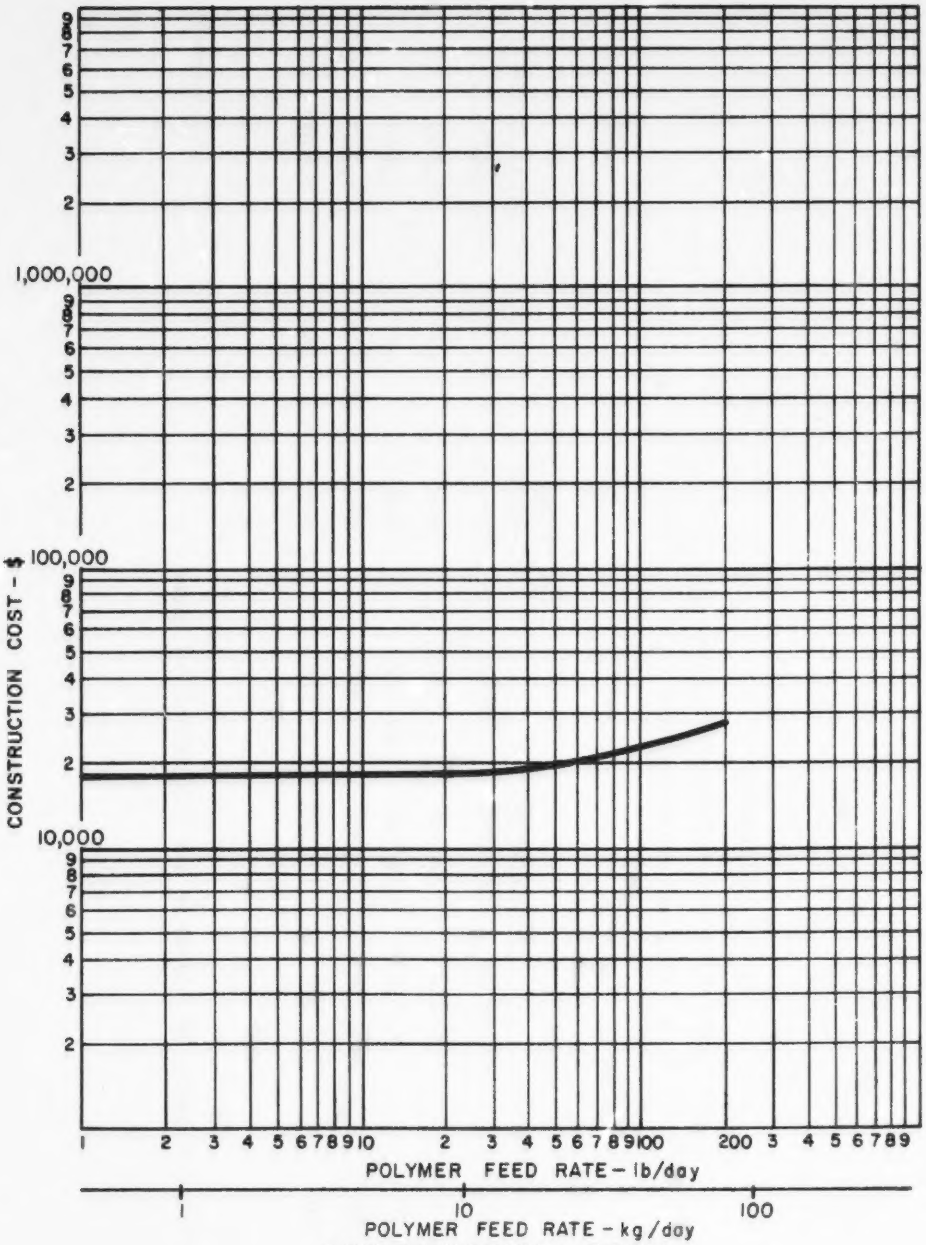
Figures 54 and 55 present the estimated operation and maintenance costs for feeding of a 0.25 percent polymer solution. The operation and maintenance requirements are summarized in Table 52.

### Table 51

### Construction Cost

### Polymer Feed Systems

| | Polymer Feed Capacity - lb/day | | | |
|---|---|---|---|---|
| | 1 | 10 | 100 | 200 |
| Manufactured Equipment | $ 11,000 | 11,000 | 13,880 | 17,880 |
| Labor | 670 | 670 | 670 | 720 |
| Pipe and Valves | 260 | 260 | 260 | 280 |
| Electrical and Instrumentation | 1,230 | 1,230 | 1,230 | 1,230 |
| Housing | 3,360 | 3,360 | 3,780 | 4,200 |
| SUBTOTAL | 16,520 | 16,520 | 19,820 | 24,310 |
| Miscellaneous and Contingency | 2,480 | 2,480 | 2,970 | 3,650 |
| TOTAL | $ 19,000 | 19,000 | 22,790 | 27,960 |



## CONSTRUCTION COST
## POLYMER FEED SYSTEMS

FIGURE 53

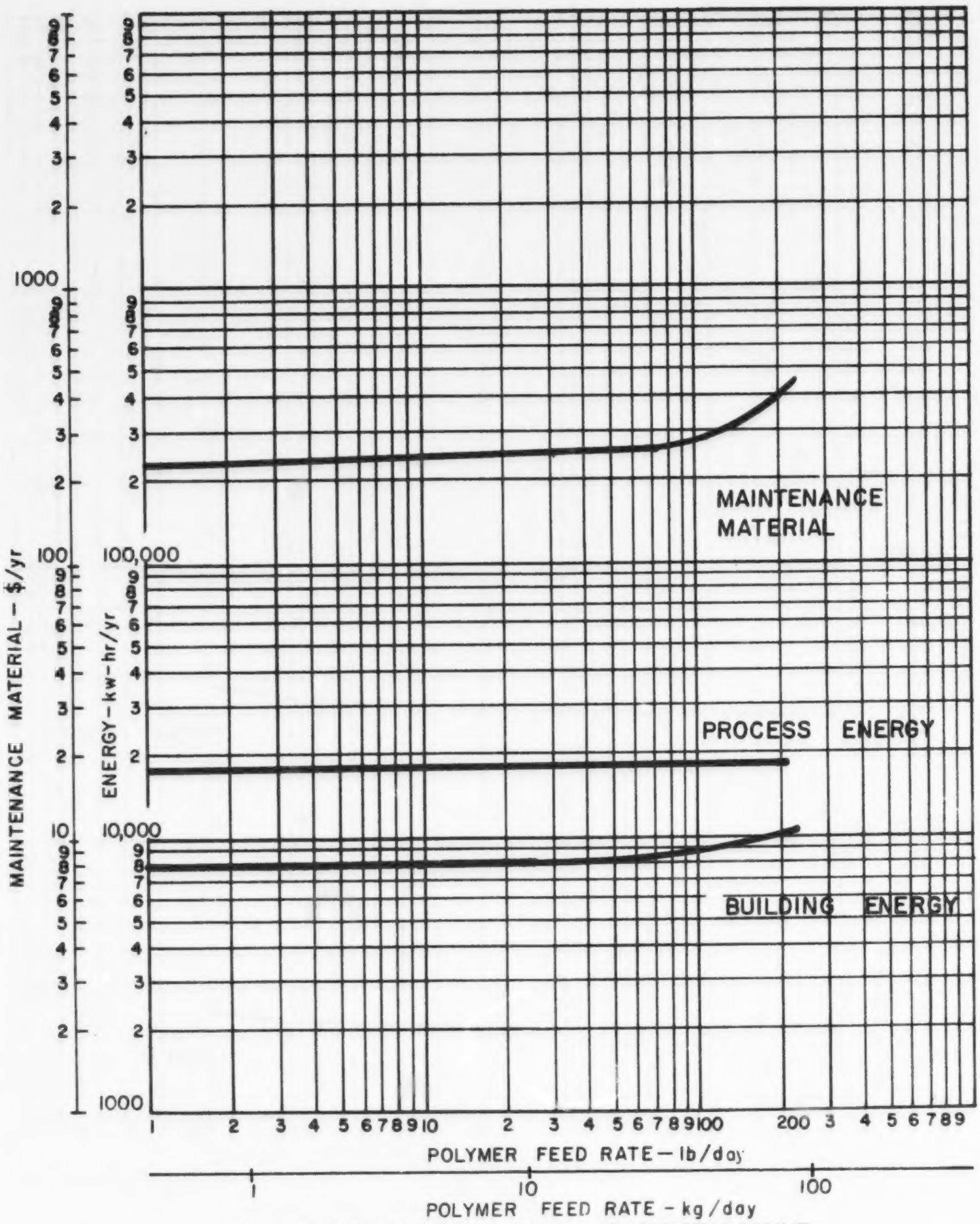
## Table 52

## Operation and Maintenance Summary

## Polymer Feed Systems

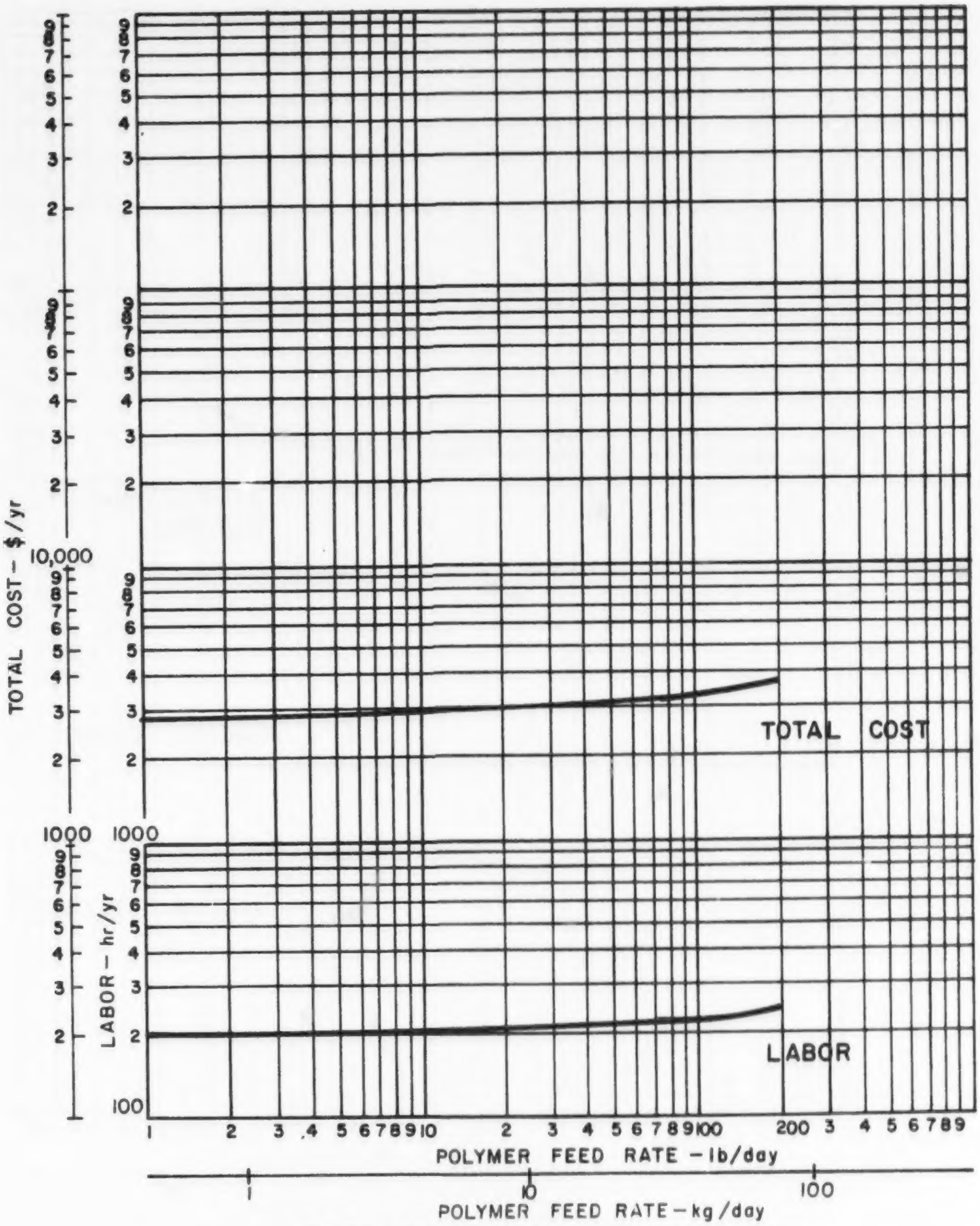
| Polymer Feed Rate lb/day | Energy kw-hr/yr | | | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| | Building | Process | Total | | | |
| 1 | 8,210 | 17,300 | 25,510 | 240 | 198 | 2,990 |
| 10 | 8,210 | 17,300 | 25,510 | 260 | 199 | 3,020 |
| 100 | 9,230 | 17,300 | 26,530 | 290 | 215 | 3,240 |
| 200 | 10,260 | 17,300 | 27,560 | 440 | 234 | 3,610 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
POLYMER FEED SYSTEMS

FIGURE 54



**OPERATION AND MAINTENANCE**
**POLYMER FEED SYSTEMS**

FIGURE 55

## CONSTRUCTION COST

### Rapid Mix

Construction costs were calculated for reinforced concrete basins ranging in size from 100 cubic feet to 20,000 cubic feet. The largest basin capacity utilized was 2,500 cubic feet, and common wall construction was utilized when more than one basin was required. Mixer costs are for vertical shaft, variable speed, turbine mixers, with 304 stainless steel shafts and paddles, and TEFC motors. Construction costs for G values of 300, 600 and 900, (3, 6, and 20 foot-pounds per second per cubic foot respectively) and a water temperature of 15°C are presented in Figure 56 and in Tables 53 to 55.

## OPERATION AND MAINTENANCE COST

### Rapid Mix

Power requirements are a function of G and water temperature. At a water temperature of 15°C and G values of 300, 600 and 900, energy requirements were calculated on the basis of respective horsepower per unit volume requirements of 3, 6, and 20 foot-pounds per second per cubic foot. An overall mechanism efficiency of 70 percent was utilized.

Maintenance material costs consist of oil for the gearbox drive unit.

Labor requirements were determined using a jar testing time of one hour per day for plants under 50 mgd and two hours per day for plants over 50 mgd, 15 minutes per mixer per day for routine O & M, and 4 hours per mixer per 6 months for oil changes. An allowance of 8 hours per basin per year was also included for draining, inspection, and cleaning.

Figures 57 and 58 show operation and maintenance curves for the rapid mix units, and a summation is presented in Table 56.

Table 53

Construction Cost

Rapid Mix G = 300

| | Total Basin Volume - ft$^3$ | | | | | |
|---|---|---|---|---|---|---|
| | 100 | 500 | 1,000 | 5,000 | 10,000 | 20,000 |
| Excavation and Sitework | $ 210 | 360 | 470 | 1,290 | 2,590 | 5,190 |
| Manufactured Equipment | 2,890 | 3,470 | 4,640 | 16,380 | 32,760 | 65,520 |
| Concrete | 370 | 820 | 1,210 | 3,410 | 6,810 | 13,630 |
| Steel | 520 | 1,220 | 1,820 | 5,070 | 10,130 | 20,260 |
| Labor | 1,170 | 2,190 | 3,240 | 8,090 | 16,190 | 32,390 |
| Electrical and Instrumentation | 6,670 | 6,670 | 6,670 | 10,280 | 19,230 | 35,990 |
| SUBTOTAL | 11,830 | 14,730 | 18,050 | 44,520 | 87,710 | 172,980 |
| Miscellaneous and Contingency | 1,770 | 2,210 | 2,710 | 6,670 | 13,160 | 25,950 |
| TOTAL | $ 13,600 | 16,940 | 20,760 | 51,190 | 100,870 | 198,930 |

## Table 54

## Construction Cost

## Rapid Mix G = 600

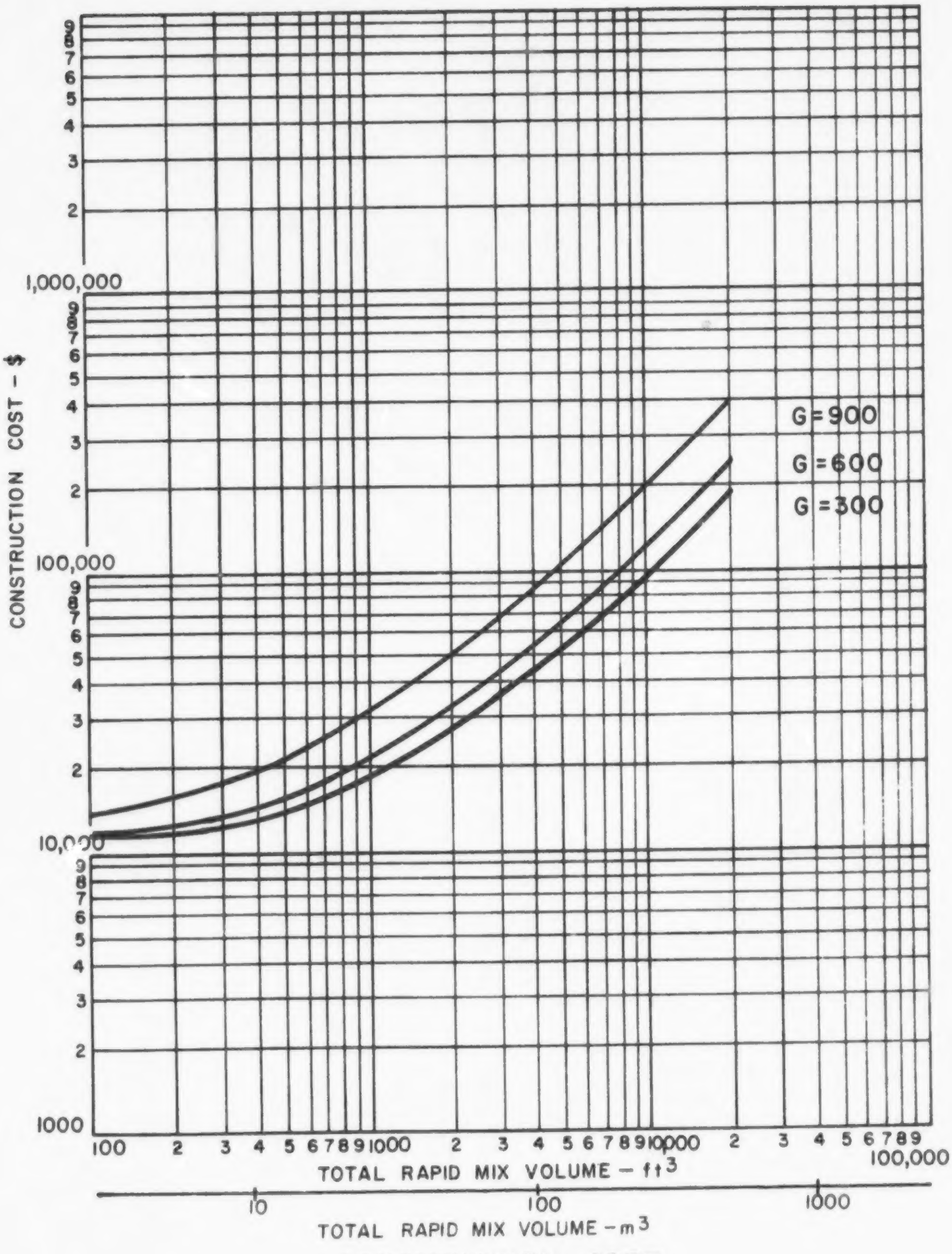
| | Total Basin Volume - ft$^3$ | | | | | |
|---|---|---|---|---|---|---|
| | 100 | 500 | 1,000 | 5,000 | 10,000 | 20,000 |
| Excavation and Sitework | $ 210 | 360 | 470 | 1,290 | 2,590 | 5,190 |
| Manufactured Equipment | 3,250 | 4,640 | 6,960 | 25,200 | 50,400 | 100,800 |
| Concrete | 370 | 820 | 1,210 | 3,410 | 6,810 | 13,630 |
| Steel | 520 | 1,220 | 1,820 | 5,070 | 10,130 | 20,260 |
| Labor | 1,240 | 2,440 | 3,680 | 8,930 | 17,860 | 35,720 |
| Electrical and Instrumentation | 6,670 | 6,670 | 6,670 | 11,060 | 19,930 | 37,760 |
| SUBTOTAL | 12,260 | 16,150 | 20,810 | 54,960 | 107,720 | 213,360 |
| Miscellaneous and Contingency | 1,840 | 2,420 | 3,120 | 8,240 | 16,160 | 32,000 |
| TOTAL | $ 14,100 | 18,570 | 23,930 | 63,200 | 123,880 | 245,360 |

## Table 55

## Construction Cost

## Rapid Mix G = 900

| | Total Basin Volume - $ft^3$ | | | | | |
|---|---|---|---|---|---|---|
| | 100 | 500 | 1,000 | 5,000 | 10,000 | 20,000 |
| Excavation and Sitework | $ 210 | 360 | 470 | 1,290 | 2,590 | 5,190 |
| Manufactured Equipment | 4,060 | 9,270 | 13,910 | 63,000 | 126,000 | 252,000 |
| Concrete | 370 | 820 | 1,210 | 3,410 | 6,810 | 13,630 |
| Steel | 520 | 1,220 | 1,820 | 5,070 | 10,130 | 20,260 |
| Labor | 1,170 | 2,190 | 3,240 | 12,500 | 25,000 | 50,000 |
| Electrical and Instrumentation | 6,670 | 6,670 | 6,860 | 7,140 | 8,370 | 15,380 |
| SUBTOTAL | 13,000 | 20,530 | 27,510 | 92,410 | 178,900 | 356,460 |
| Miscellaneous and Contingency | 1,950 | 3,080 | 4,130 | 13,860 | 26,840 | 53,470 |
| TOTAL | $ 14,950 | 23,610 | 31,640 | 106,270 | 205,740 | 409,930 |



**CONSTRUCTION COST**
**RAPID MIX**

**FIGURE 56**

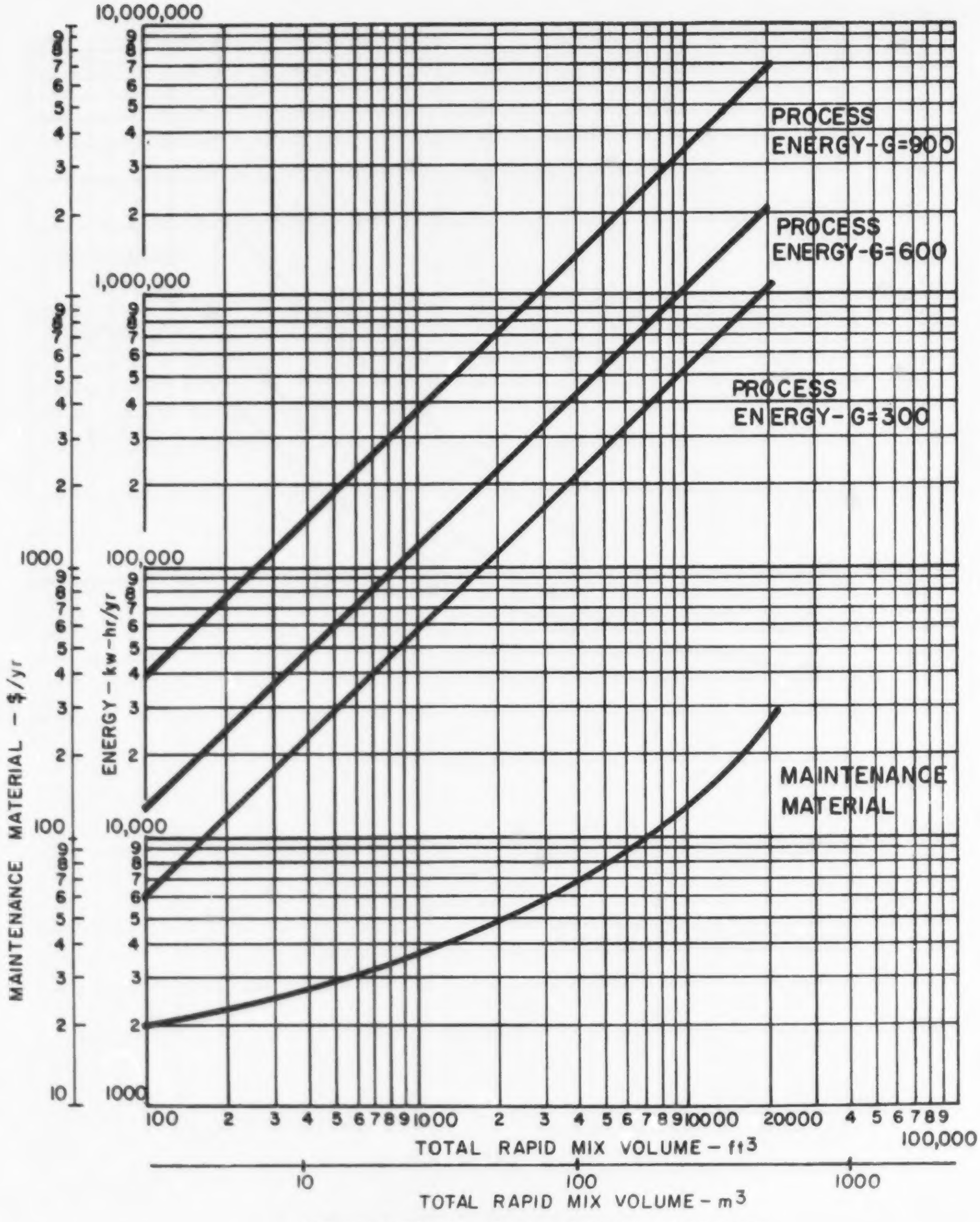
## Table 56

## Operation and Maintenance Summary

## Rapid Mix

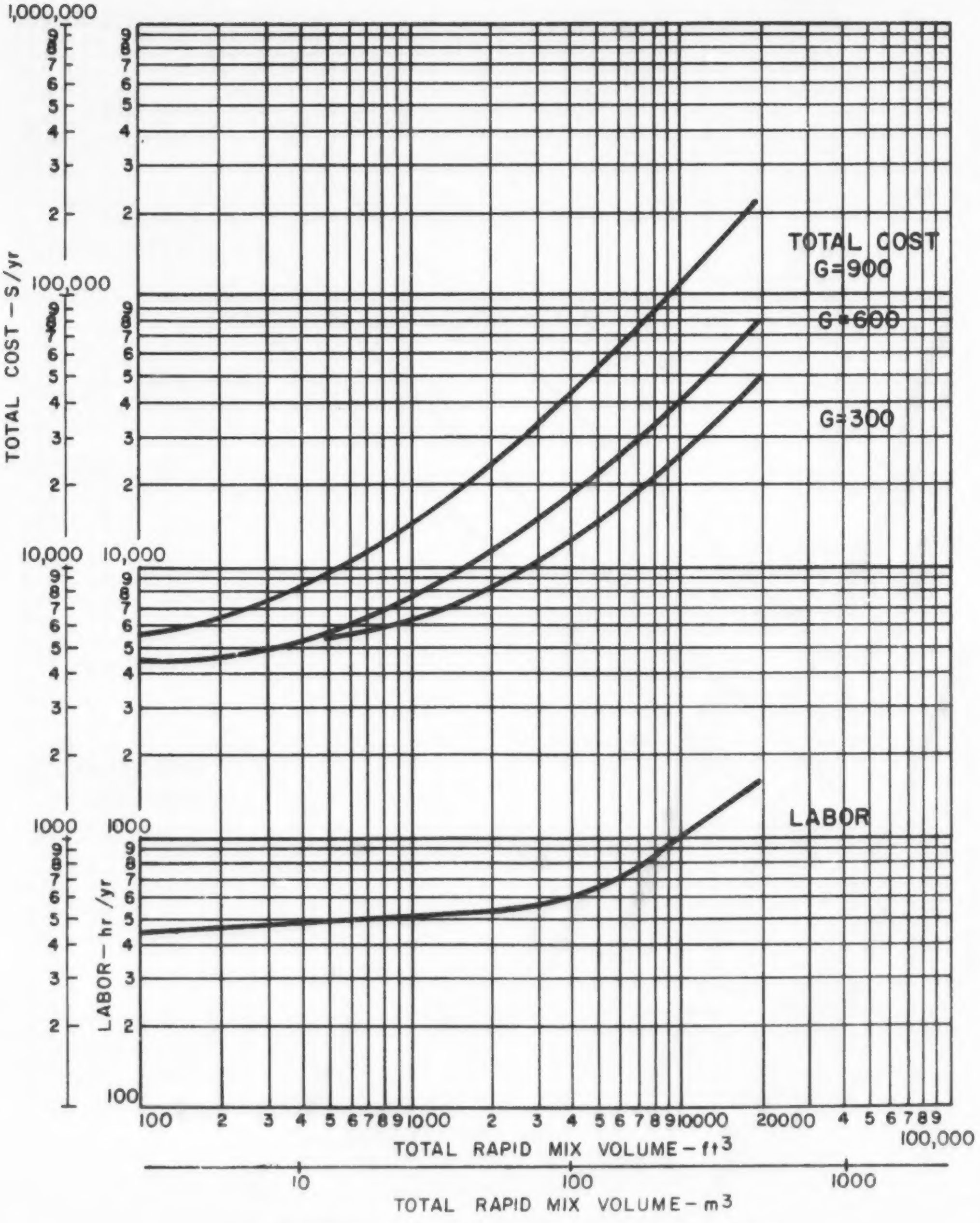
| Total Basin Volume - $ft^3$ | Energy kw-hr/yr |  |  | Maintenance Material $/yr | Labor hr/yr | Total Cost - $/yr* |  |  |
|---|---|---|---|---|---|---|---|---|
|  | G = 300 | G = 600 | G = 900 |  |  | G = 300 | G = 600 | G = 900 |
| 100 | 5,090 | 10,180 | 33,930 | 20 | 470 | 4,870 | 5,030 | 5,740 |
| 500 | 25,450 | 50,900 | 169,670 | 30 | 470 | 5,490 | 6,260 | 9,820 |
| 1,000 | 50,900 | 101,800 | 339,330 | 40 | 470 | 6,270 | 7,790 | 14,920 |
| 2,500 | 127,250 | 254,500 | 848,330 | 60 | 510 | 8,980 | 12,800 | 30,610 |
| 5,000 | 254,500 | 509,000 | 1,696,700 | 75 | 580 | 13,510 | 21,150 | 56,780 |
| 10,000 | 509,000 | 1,018,000 | 3,393,300 | 150 | 1,160 | 27,020 | 42,290 | 113,550 |
| 20,000 | 1,018,000 | 2,036,000 | 6,786,670 | 300 | 1,590 | 46,740 | 77,280 | 219,800 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
RAPID MIX

FIGURE 57



**OPERATION AND MAINTENANCE**
**RAPID MIX**

FIGURE 58

## CONSTRUCTION COST

### Flocculation

Estimated flocculation basin costs are for rectangular shaped reinforced concrete structures, 12 feet deep, with common wall construction where the total basin volume exceeded 12,500 cubic feet. A length to width ratio of approximately 4:1 was used for basin sizing and the maximum basin size utilized was 12,500 cubic feet. Structural costs for vertical turbine flocculators are somewhat higher than for the horizontal paddle type due to the required structural support above the basin. Costs were calculated for use of horizontal paddle flocculators and total basin volumes between 1,800 and 1,000,000 cubic feet, but only between 1,800 and 25,000 cubic feet for vertical turbine type. Horizontal paddles are less expensive for use in larger basins, and generally provide more satisfactory operation in the larger basins, particularly when tapered flocculation is practiced.

G values of 20, 50 and 80 were used to calculate manufactured equipment costs. All drive units are variable speed, to allow maximum flexibility. Although common drive for two or more parallel basins is commonly utilized, the estimated costs were calculated using individual drive for each basin. Estimated costs for horizontal paddle systems are shown in Figure 59 and on Tables 57 to 59 and for vertical turbine flocculators in Figure 60 and on Table 60.

## OPERATION AND MAINTENANCE COST

### Flocculation

Energy requirements for G values of 20, 50 and 80 were calculated on the basis of respective horsepower per unit volume requirements of 0.01, 0.06 and 0.17 foot-pounds per second per cubic foot. An overall motor/mechanism efficiency of 60 percent was utilized.

Maintenance material costs are based upon 3 percent of the manufactured equipment costs. Although equipment costs vary somewhat with the maximum design value for G, the maintenance material costs are based upon a G value of 80.

Labor requirements are based on routine O & M of 15 minutes per day per basin (maximum basin volume = 12,500 cubic feet) and an oil change every six months requiring four hours per change. No allowance is included for jar test time, as this is included in the rapid mix O & M curves.

Figures 61 and 62 present operation and maintenance costs for G = 20, 50 and 80 for horizontal paddle flocculation. Costs for vertical turbine flocculators are nearly identical, and are not shown separately. However, the cost curves are applicable to vertical turbine flocculators only up to basin volumes of 25,000 cubic feet. Table 61 summarizes the operation and maintenance requirements.

## Table 57

## Construction Cost

## Flocculation - Horizontal Paddle G = 20

| | Total Basin Volume - ft$^3$ | | | | | |
|---|---|---|---|---|---|---|
| | 1,800 | 10,000 | 25,000 | 100,000 | 500,000 | 1,000,000 |
| Excavation and Sitework | $ 450 | 2,430 | 4,080 | 9,490 | 38,130 | 73,870 |
| Manufactured Equipment | 11,440 | 26,620 | 29,620 | 51,370 | 111,560 | 219,370 |
| Concrete | 1,320 | 7,180 | 12,020 | 28,090 | 113,480 | 219,790 |
| Steel | 2,140 | 11,370 | 18,520 | 42,140 | 158,840 | 307,640 |
| Labor | 6,740 | 19,240 | 26,740 | 66,540 | 178,260 | 355,280 |
| Electrical and Instrumentation | 6,670 | 27,050 | 27,050 | 27,050 | 135,270 | 270,540 |
| SUBTOTAL | 28,760 | 93,890 | 118,030 | 224,680 | 735,540 | 1,446,490 |
| Miscellaneous and Contingency | 4,310 | 14,080 | 17,700 | 33,700 | 110,330 | 216,970 |
| TOTAL | $ 33,070 | 107,970 | 135,730 | 258,380 | 845,870 | 1,663,460 |

## Table 58

## Construction Cost

## Flocculation - Horizontal Paddle G = 50

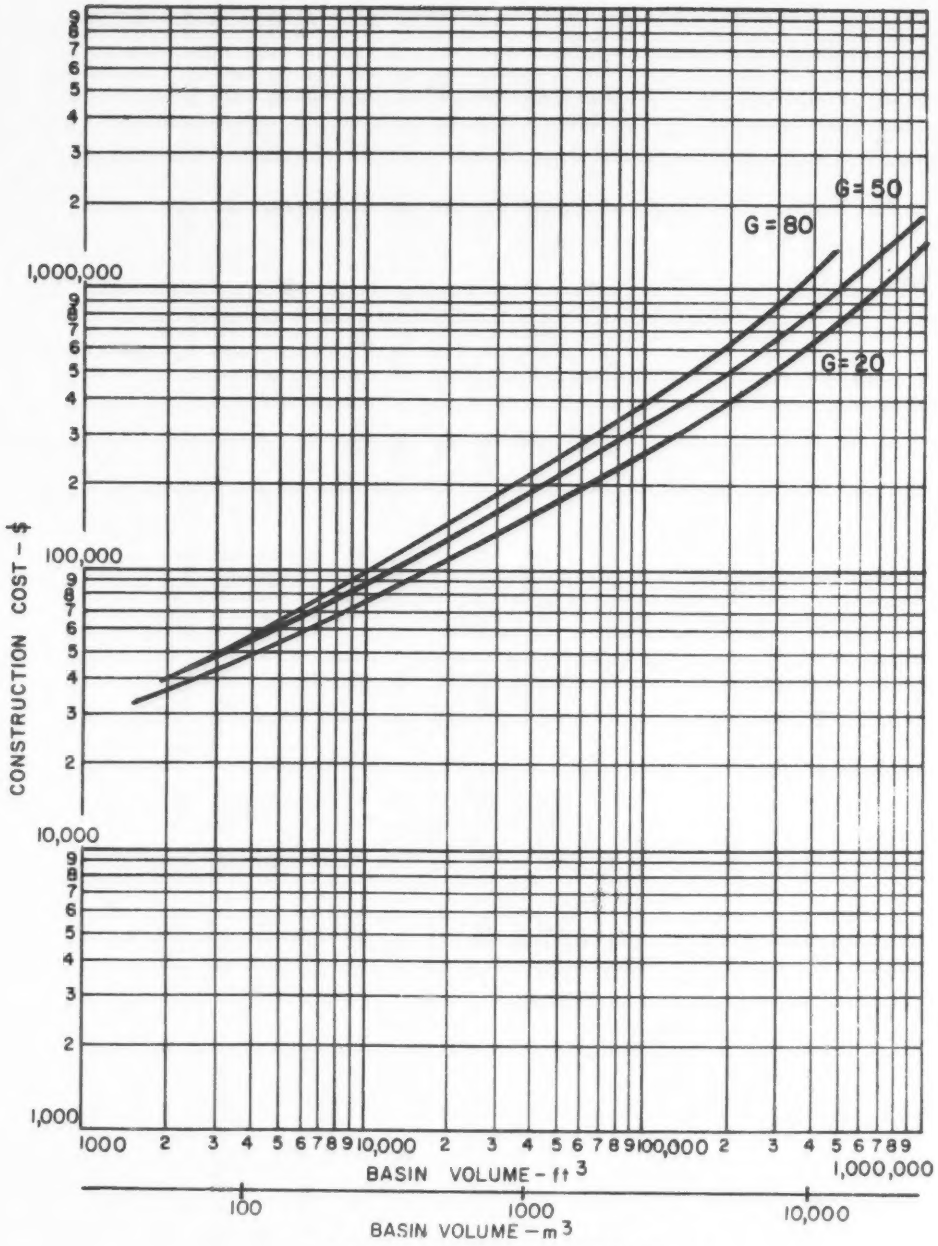
| | Total Basin Volume - $ft^3$ | | | | | |
|---|---|---|---|---|---|---|
| | 1,800 | 10,000 | 25,000 | 100,000 | 500,000 | 1,000,000 |
| Excavation and Sitework | $ 450 | 2,430 | 4,080 | 9,490 | 38,130 | 73,870 |
| Manufactured Equipment | 11,440 | 26,630 | 33,380 | 70,130 | 208,130 | 408,750 |
| Concrete | 1,320 | 7,180 | 12,020 | 28,090 | 113,480 | 219,790 |
| Steel | 2,140 | 11,370 | 18,520 | 42,140 | 158,840 | 307,640 |
| Labor | 6,740 | 19,240 | 27,990 | 71,790 | 210,450 | 418,400 |
| Electrical and Instrumentation | 6,670 | 27,050 | 27,050 | 27,050 | 135,270 | 270,540 |
| SUBTOTAL | 28,760 | 93,900 | 123,040 | 248,690 | 864,300 | 1,698,990 |
| Miscellaneous and Contingency | 4,310 | 14,090 | 18,460 | 37,300 | 129,650 | 254,850 |
| TOTAL | $ 33,070 | 107,990 | 141,500 | 285,990 | 993,950 | 1,953,840 |

## Table 59

## Construction Cost

## Flocculation - Horizontal Paddle G = 80

| | Total Basin Volume - ft$^3$ | | | | |
|---|---|---|---|---|---|
| | 1,800 | 10,000 | 25,000 | 100,000 | 500,000 |
| Excavation and Sitework | $ 450 | 2,430 | 4,080 | 9,490 | 38,130 |
| Manufactured Equipment | 11,440 | 32,250 | 41,810 | 109,130 | 403,130 |
| Concrete | 1,320 | 7,180 | 12,020 | 28,090 | 113,480 |
| Steel | 2,140 | 11,370 | 18,520 | 42,140 | 158,840 |
| Labor | 6,740 | 21,110 | 30,800 | 85,790 | 275,450 |
| Electrical and Instrumentation | 6,670 | 27,050 | 27,050 | 27,050 | 135,270 |
| SUBTOTAL | 28,760 | 101,390 | 134,280 | 301,690 | 1,124,300 |
| Miscellaneous and Contingency | 4,310 | 15,210 | 20,140 | 45,250 | 168,650 |
| TOTAL | $ 33,070 | 116,600 | 154,420 | 346,940 | 1,292,950 |



CONSTRUCTION COST
FLOCCULATION - HORIZONTAL PADDLE

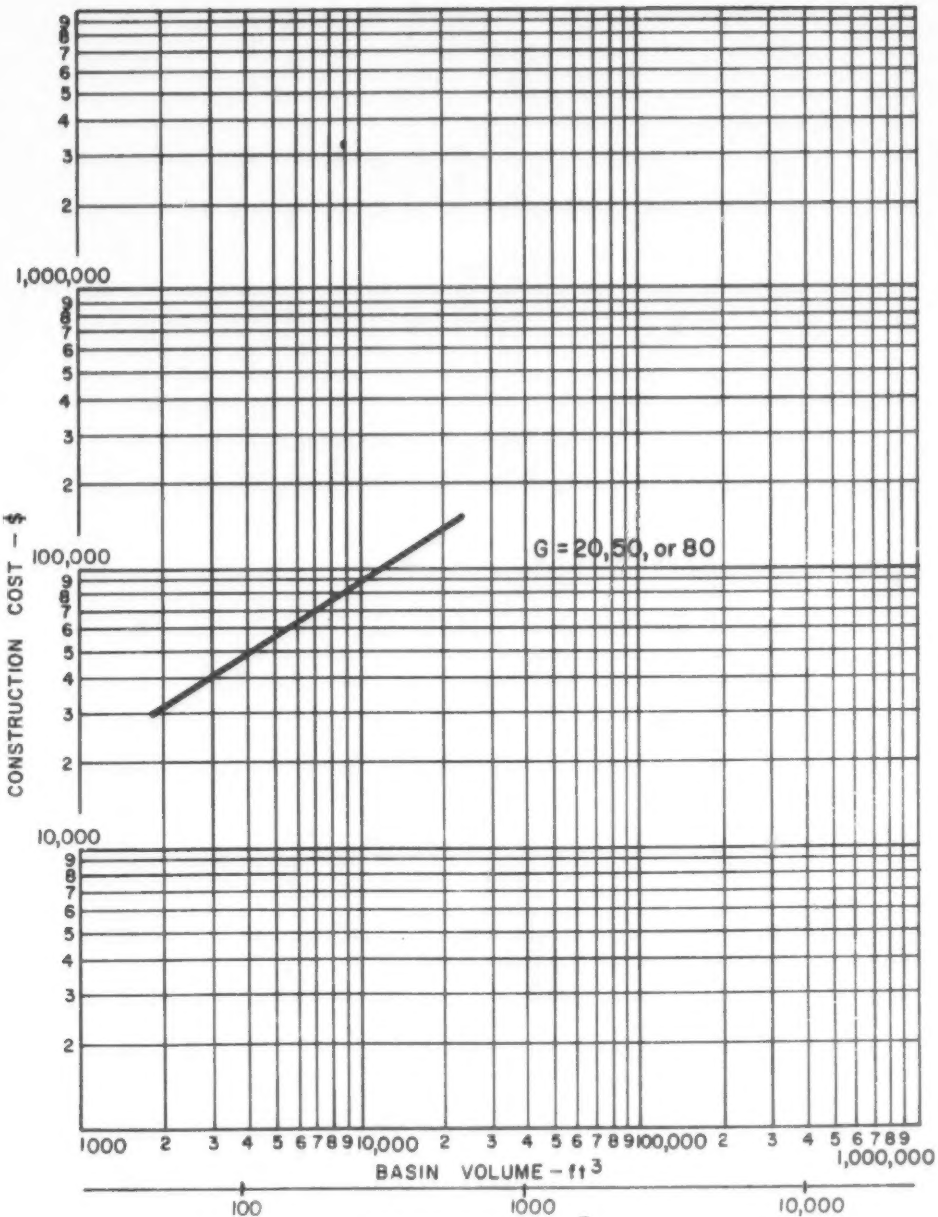
FIGURE 59

Table 60

Construction Cost

Flocculation - Vertical Turbine

| | Total Basin Volume - ft$^3$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1,800 ft$^3$ | | | 10,000 ft$^3$ | | | 25,000 ft$^3$ | | |
| | G=20 | G=50 | G=80 | G=20 | G=50 | G=80 | G=20 | G=50 | G=80 |
| Excavation and Sitework | $ 600 | 600 | 600 | 2,400 | 2,400 | 2,400 | 3,090 | 3,090 | 3,090 |
| Manufactured Equipment | 6,880 | 6,880 | 6,880 | 13,800 | 15,000 | 15,000 | 27,500 | 27,500 | 32,500 |
| Concrete | 1,820 | 1,820 | 1,820 | 7,280 | 7,280 | 7,280 | 11,600 | 11,600 | 11,600 |
| Steel | 2,870 | 2,870 | 2,870 | 11,300 | 11,300 | 11,300 | 17,580 | 17,580 | 17,580 |
| Labor | 6,890 | 6,890 | 6,890 | 21,030 | 21,380 | 21,380 | 35,270 | 35,270 | 36,520 |
| Electrical and Instrumentation | 6,670 | 6,670 | 6,670 | 27,050 | 27,050 | 27,050 | 27,050 | 27,050 | 27,050 |
| SUBTOTAL | 25,730 | 25,730 | 25,730 | 82,860 | 84,060 | 84,060 | 122,090 | 122,090 | 127,090 |
| Miscellaneous and Contingency | 3,860 | 3,860 | 3,860 | 12,430 | 12,610 | 12,610 | 18,310 | 18,310 | 19,060 |
| TOTAL | $ 29,590 | 29,590 | 29,590 | 95,290 | 96,670 | 96,670 | 140,400 | 140,400 | 146,150 |



CONSTRUCTION COST
FLOCCULATION—VERTICAL TURBINE

FIGURE 60

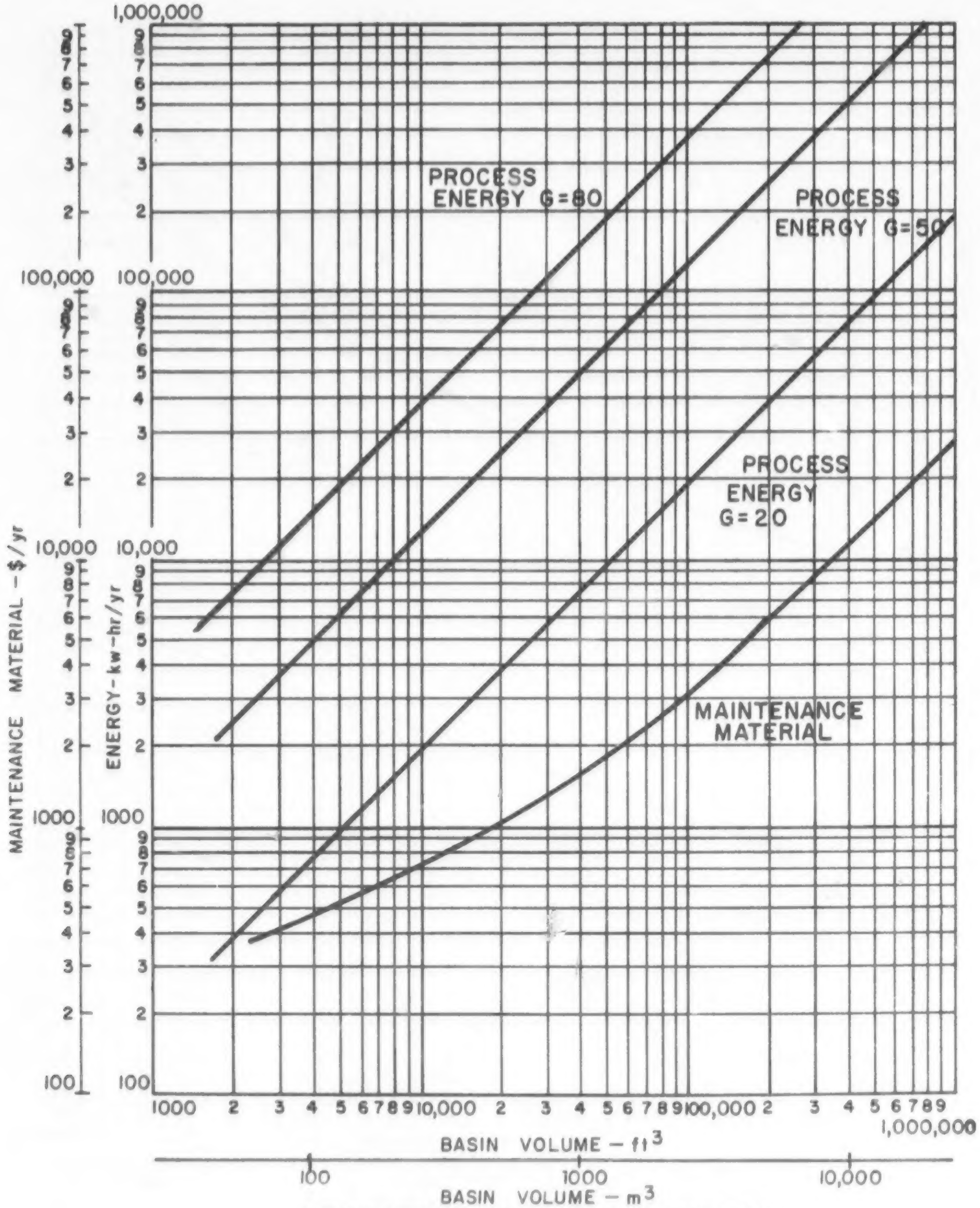
## Table 61

## Operation and Maintenance Summary

## Flocculation

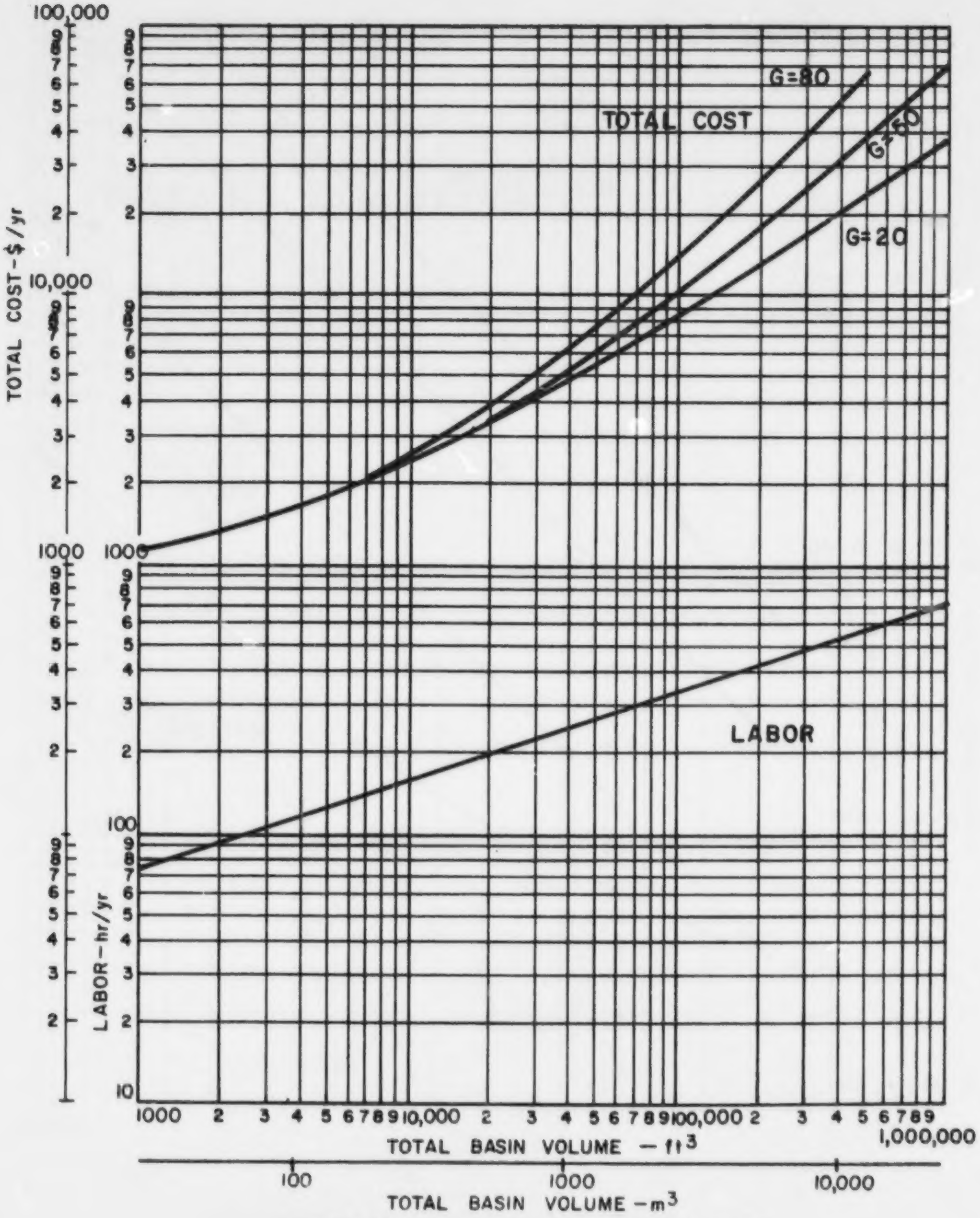
| Total Basin Volume - $ft^3$ | Energy kw-hr/yr |  |  | Maintenance Material $/yr | Labor hr/yr | Total Cost - $/yr* |  |  |
|---|---|---|---|---|---|---|---|---|
|  | G = 20 | G = 50 | G = 80 |  |  | G = 20 | G = 50 | G = 80 |
| 1,800 | 330 | 2,070 | 6,100 | 380 | 99 | 1,380 | 1,430 | 1,550 |
| 10,000 | 1,960 | 11,870 | 33,660 | 980 | 199 | 3,030 | 3,330 | 3,980 |
| 25,000 | 4,900 | 29,630 | 84,080 | 980 | 199 | 3,120 | 3,860 | 5,490 |
| 100,000 | 19,600 | 118,720 | 336,550 | 3,750 | 397 | 8,310 | 11,280 | 17,820 |
| 500,000 | 98,020 | 593,590 | 1,682,750 | 13,500 | 496 | 21,400 | 36,270 | 68,940 |
| 1,000,000 | 198,230 | 1,188,300 | -- | 27,000 | 990 | 42,850 | 72,550 | -- |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
FLOCCULATION

FIGURE 61



OPERATION AND MAINTENANCE
FLOCCULATION

FIGURE 62

## CONSTRUCTION COST

### Gravity Filtration Structure

Conventional gravity filtration structure costs are based upon use of cast in place concrete with a media depth of 2 to 3 feet, and a total depth of 16 feet for the filter box. Construction cost estimates have been based on the conceptual designs outlined in Table 62. At flows less than 5 mgd, two filters were used, but at 5 mgd and greater, a minimum of four filters was utilized. Maximum filter size was limited to 1,275 square feet and above 700 square feet the filters are dual-celled to allow backwashing of each half separately. This approach allows a significant reduction in the size of wash water and waste piping. On the designs up to and including 10 mgd, raw water was fed to the filter using a gullet between the pipe gallery and the filter structure. For larger designs, which were dual-celled, raw water was fed using an influent channel located on the periphery of the filter structure. Only one valve was used to admit raw water to the dual-celled filters, since the filters operate as one until the end of the filter cycle, even though they are backwashed separately. For designs up to and including 10 mgd, piping was used to convey product water in the pipe gallery, but larger designs used a covered concrete box structure in the center of the pipe gallery. Basic housing requirements includes housing only the pipe gallery, which is located beneath the filter control area. The filter structure need not be housed except in severe winter climates, where other precautions such as diffused air addition near the filter periphery are not taken. The cost curves include, however, housing of the entire filter structure.

Costs for filtration structures are presented in Table 63 and Figure 63. These costs include the filter structure, underdrains, wash water troughs, a pipe gallery, required piping and cylinder operated butterfly valves, filter flow and headloss instrumentation, a filter control panel, and the total housing requirement. The costs do not include the cost of backwash water storage facilities, backwash pumping facilities, filtration media, or surface wash piping and pumps. These facilities were not included since their use and sizing will vary with each design, and they are most appropriately added separately.

## OPERATION AND MAINTENANCE COST

### Gravity Filtration Structure

Energy requirements are only for building heating, ventilation, and lighting. All process energy required for filtration is included in the backwash and surface wash curves.

Maintenance material includes the cost of general supplies, instrumentation repair and the periodic addition of filter media. Costs are based upon costs experienced at several plants.

Labor costs include the cost of operation, as well as the cost of instrument and equipment repairs, and supervision.

## Table 62

## Conceptual Designs for Gravity Filtration Structures

## (24 to 36 Inch Media Depth)

| Plant Flow, mgd | Total Filter Area Ft$^2$ | Filters | | Housing Requirement - Ft$^2$ | |
|---|---|---|---|---|---|
| | | Number | Area Each, Ft$^2$ | Basic | Total |
| 1 | 140 | 2 | 70 | 150 | 430 |
| 5 | 700 | 4 | 175 | 420 | 1,480 |
| 10 | 1,400 | 4 | 350 | 800 | 2,720 |
| 50 | 7,000 | 10 | 700* | 2,900 | 11,600 |
| 100 | 14,000 | 14 | 1,000* | 4,060 | 21,110 |
| 200 | 28,000 | 22 | 1,275* | 6,380 | 40,190 |

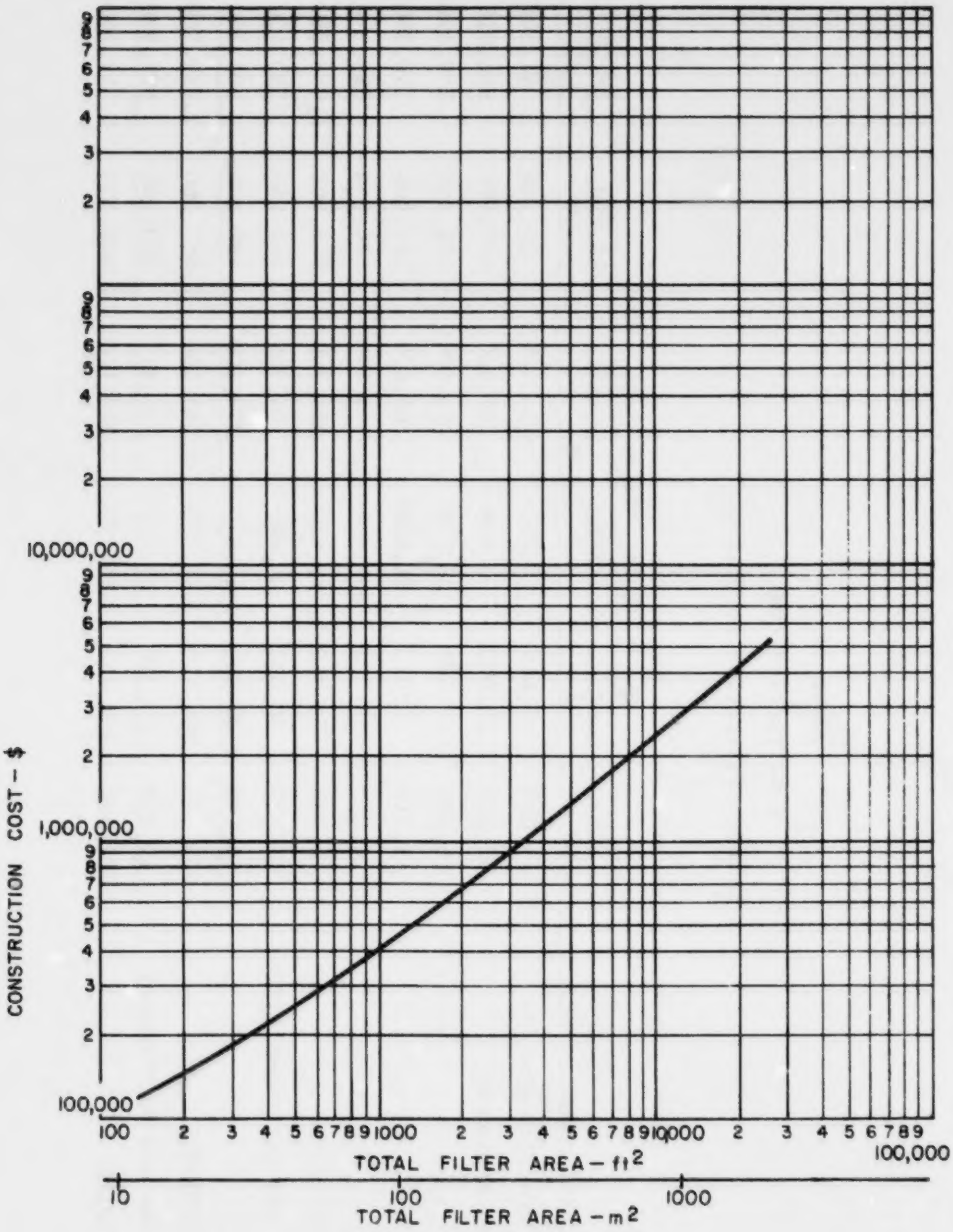
*Dual celled filters

## Table 63

## Construction Cost

## Gravity Filtration Structure

|  | Total Filter Area - $ft^2$ |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | 140 | 700 | 1,400 | 7,000 | 14,000 | 28,000 |
| Plant Flow Rate - mgd | 1 | 5 | 10 | 50 | 100 | 200 |
| Excavation and Sitework | $ 1,860 | 3,440 | 5,250 | 15,430 | 24,350 | 41,300 |
| Manufactured Equipment | 22,210 | 53,690 | 73,810 | 287,660 | 498,980 | 926,010 |
| Concrete | 6,750 | 17,100 | 26,270 | 93,580 | 152,050 | 259,990 |
| Steel | 5,210 | 9,050 | 16,020 | 66,630 | 111,600 | 190,250 |
| Labor | 21,260 | 56,700 | 104,330 | 339,070 | 484,250 | 985,380 |
| Pipe and Valves | 19,360 | 74,340 | 119,800 | 395,760 | 555,200 | 1,058,850 |
| Electrical and Instrumentation | 12,790 | 36,690 | 36,690 | 94,700 | 161,280 | 253,430 |
| Housing | 16,250 | 37,800 | 65,910 | 272,600 | 480,250 | 904,350 |
| SUBTOTAL | 105,690 | 288,810 | 448,080 | 1,565,430 | 2,467,960 | 4,619,560 |
| Miscellaneous and Contingency | 15,850 | 43,320 | 67,210 | 234,810 | 370,190 | 692,930 |
| TOTAL | $ 121,540 | 332,130 | 515,290 | 1,800,240 | 2,838,150 | 5,312,490 |



CONSTRUCTION COST
GRAVITY FILTRATION STRUCTURE

FIGURE 63

Figures 64 and 65 present the operation and maintenance requirements, and Table 64 is a summation of these requirements.

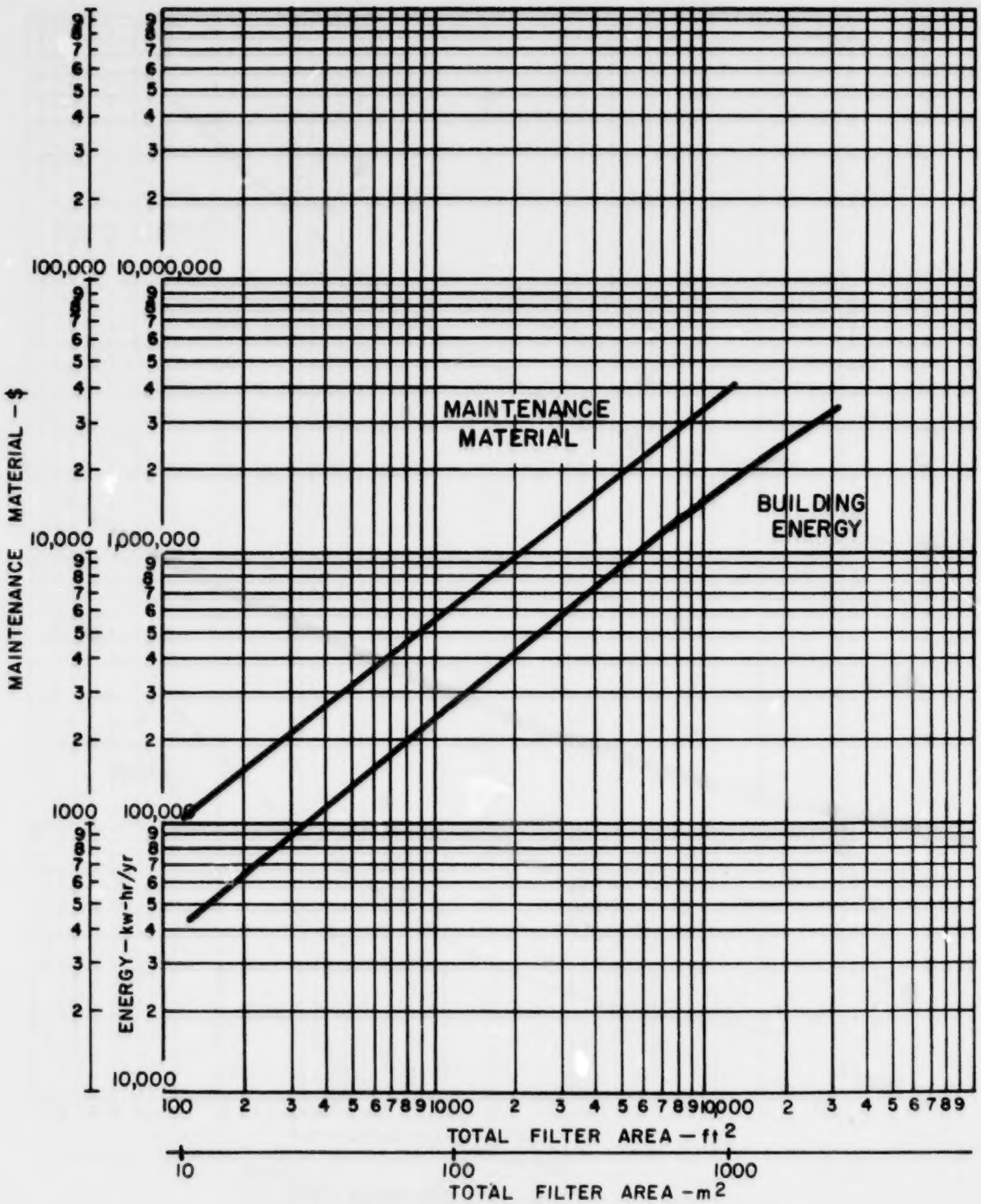
## Table 64

## Operation and Maintenance Summary

## Gravity Filtration Structure

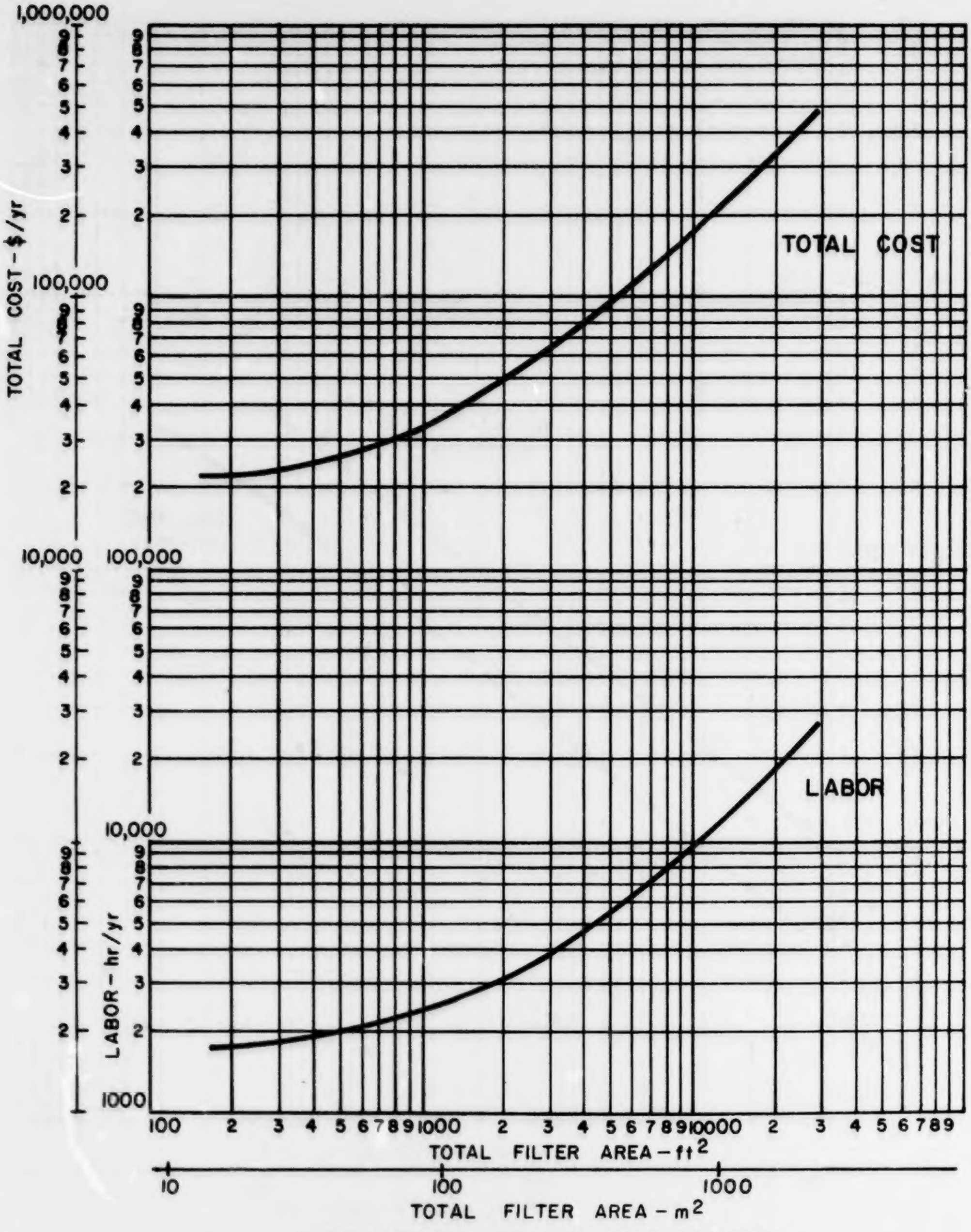
| Total Filter Area - $ft^2$ | Energy kw-hr/yr | Maintenance Material - $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|
| 140 | 44,120 | 1,100 | 1,825 | 20,670 |
| 700 | 151,850 | 3,850 | 2,190 | 30,310 |
| 1,400 | 279,070 | 7,060 | 2,570 | 41,130 |
| 7,000 | 1,190,160 | 26,400 | 6,600 | 128,100 |
| 14,000 | 2,165,890 | 44,000 | 13,000 | 238,980 |
| 28,000 | 4,123,490 | 80,300 | 25,500 | 459,000 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
GRAVITY FILTRATION STRUCTURE

FIGURE 64



**OPERATION AND MAINTENANCE**
**GRAVITY FILTRATION STRUCTURE**

**FIGURE 65**

## CONSTRUCTION COST

### Filtration Media

Cost estimates have been prepared for three types of commonly used filtration media: rapid sand, dual media (coal-sand), and mixed media (coal-sand-garnet). The advantage of rapid sand media is its low initial cost and simplicity of placement while its disadvantages are the relatively low application rates and limited suspended solids loading. While the more sophisticated dual and mixed media allow higher filtration rates and suspended solids loading than rapid sand, they are higher in initial cost and require in place processing. Common practice is to backwash the media during placement and then skim a shallow layer from the surface to remove excessive fines.

Cost estimates have been made for purchase and placement of 30-inches of media over a 12-inch gravel underdrain. These estimates are applicable to either gravity or pressure filters, although pressure filters are often designed with a somewhat deeper gravel support layer. Characteristics of each media and the gravel underdrain are presented in Table 65. Costs were developed as a function of filter area using a filtration rate of 2 gpm/square foot for rapid sand, and 5 gpm/square foot for dual media and mixed media. For plants with total filter areas of 140 square feet and less, materials were considered to be truck shipped in 100 pound bags. For total filter areas between 140 and 2,000 square feet, rail shipment in 100 pound bags was assumed, and for larger filter areas, rail shipment by bulk was assumed.

The estimated costs include media cost, shipping, and installation. Where required, the cost of a trained technician to supervise media placement is also included. Freight cost represents a nationwide average. Estimated filtration media costs are presented in Figure 66 and in Table 66.

## Table 65

## Filter Media and Gravel Underdrain Characteristics

Rapid Sand:

30 inches of 0.42 - 0.55 mm effective size silica sand, uniformity coefficient less than 1.6.

Dual Media:

20 inches of 1.0 - 1.2 mm effective size anthracite coal, uniformity coefficient less than 1.7.

10 inches of 0.42 - 0.55 mm effective size silica sand, uniformity coefficient less than 1.6.

Mixed (Tri) Media:

16-1/2 inches of 1.0 - 1.1 mm effective size anthracite coal, uniformity coefficient less than 1.7.

9 inches of 0.42 - 0.55 mm effective size silica sand, uniformity coefficient less than 1.6.

4-1/2 inches of 0.18 - 0.28 mm effective size garnet or ilmenite sand, uniformity coefficient less than 1.8.

Gravel Underdrain: (common to all four media)

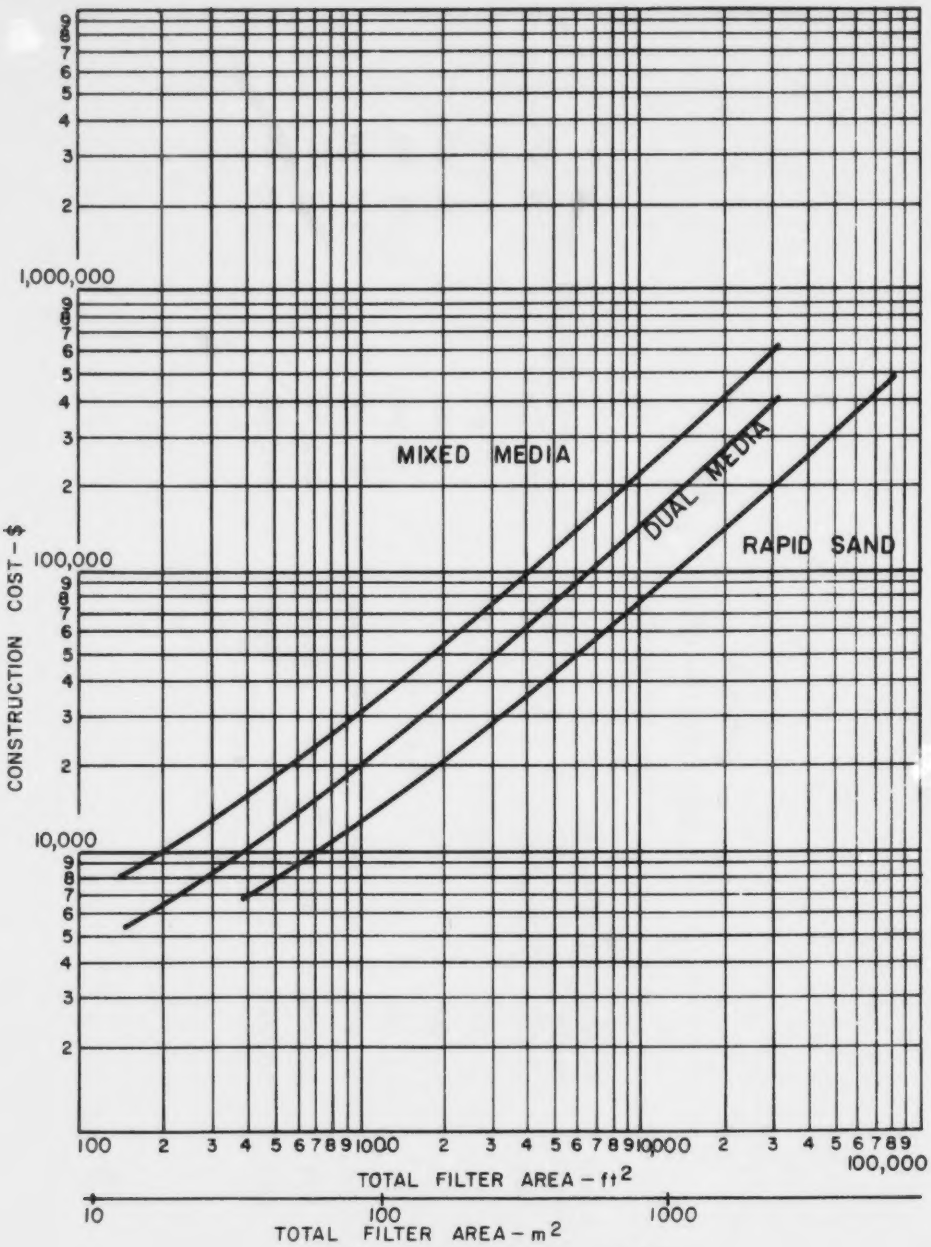
3 inches of 1-1/2" x 3/4" silica gravel
3 inches of 3/4" x 3/8" silica gravel
3 inches of 3/8" x 3/16" silica gravel
3 inches of 3/16" x #10 silica gravel

## Table 66

## Construction Cost

## Filtration Media

| Plant Capacity mgd | Filter Bed Area, $ft^2$ |  | Filter Media Costs Installed |  |  |
|---|---|---|---|---|---|
|  | Rapid Sand | Dual and Mixed Media | Rapid Sand | Dual Media | Mixed Media |
| 1 | 350 | 140 | 6,080 | 5,430 | 8,420 |
| 5 | 1,750 | 700 | 24,570 | 16,990 | 24,060 |
| 10 | 3,500 | 1,400 | 27,190 | 30,900 | 45,700 |
| 50 | 17,500 | 7,000 | 131,490 | 106,590 | 169,690 |
| 100 | 35,000 | 14,000 | 262,210 | 203,360 | 332,560 |
| 200 | 70,000 | 28,000 | 523,640 | 403,420 | 654,580 |



CONSTRUCTION COST
FILTRATION MEDIA

FIGURE 66

## CONSTRUCTION COST

### Hydraulic Surface Wash Systems

The cost of hydraulic surface wash systems is presented separately from the backwash system, as some plants may not use surface wash in conjunction with backwashing. If surface wash is utilized, the cost must be added to the cost of the backwash system, the filter structure, and the filter media, to arrive at the total cost of filtration. Cost estimates include dual pumps with one as standby, electrical control, piping, valves, and headers within the filter pipe gallery. No allowance for housing is included as this is included in the filtration structure cost. Surface wash pumps are sized to provide approximately 50 to 85 psi at the arms in accordance with manufacturers recommendations.

Costs are based on the area of each individual filter within a plant, using the filter sizes presented in the gravity filter section. Dual arm agitators were used with an application rate according to manufacturers recommendations. One agitator was included for filter areas up to and including 75 square feet, four agitators for the 350 to 700 square foot filters, and 6 and 8 for the 1,000 and 1,275 square foot filters respectively. It was assumed that the wet well for the surface wash pumps is the same as for the backwash pumps. The construction cost estimates are shown by cost component in Table 67 and graphically in Figure 67.

## OPERATION AND MAINTENANCE COSTS

### Hydraulic Surface Wash Systems

Energy requirements per surface wash were calculated using a surface wash time of 8 minutes, application rates as recommended by manufacturers, which were approximately 1.5 gpm/square foot of filter surface for the dual arm agitators, a TDH of 200 feet, and an overall motor pump efficiency of 70 percent.

Maintenance material requirements are for repair of the pump(s), motor starter, valves and surface agitators. Two surface wash operations per day were assumed.

Labor requirements are for maintenance of equipment only, and are based upon manufacturers estimates. Operation labor is included with the basic filter.

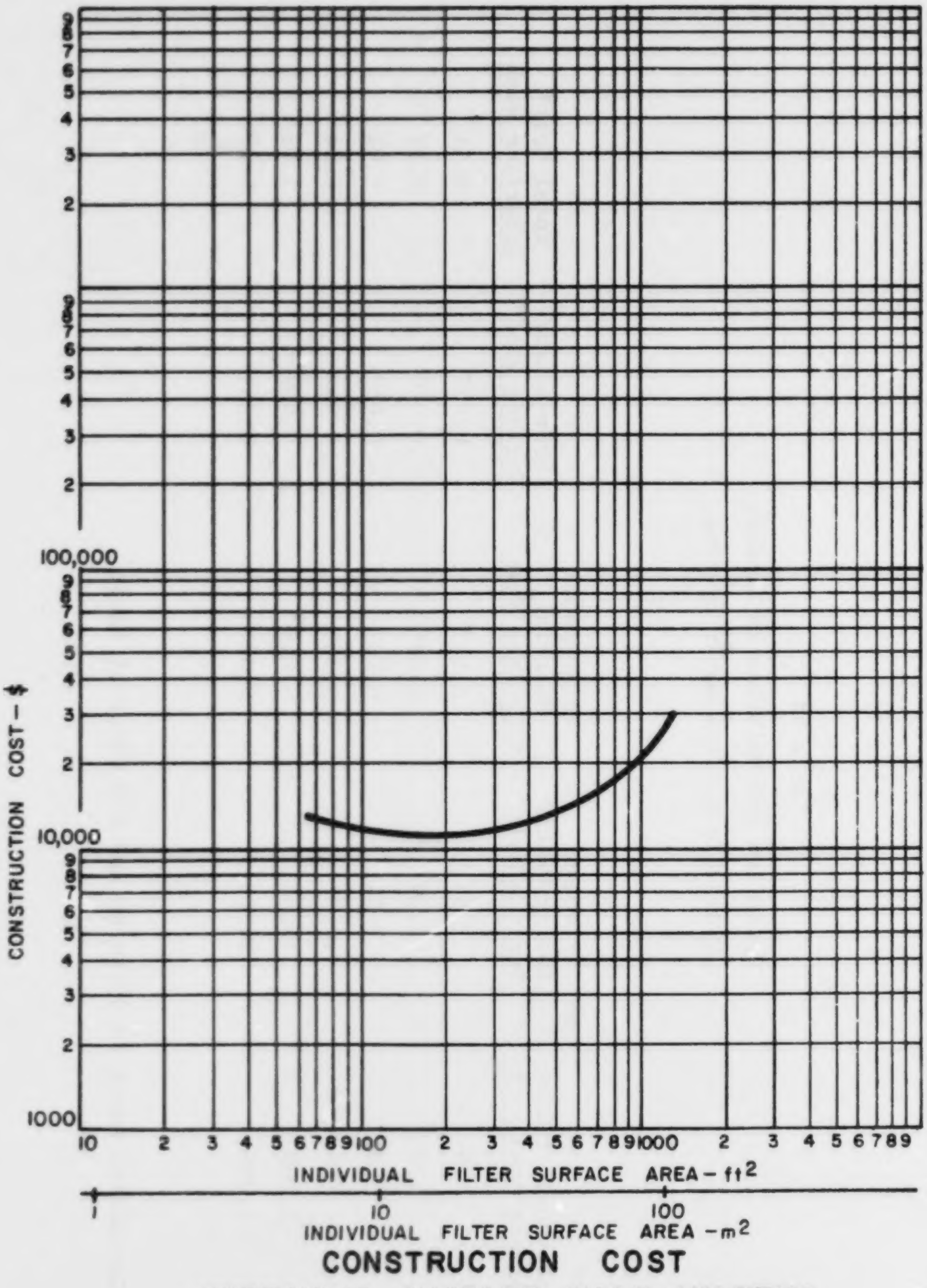
Figures 68 and 69 present the operation/maintenance requirement for hydraulic surface wash systems. The total cost must be added to the costs for filter backwashing and filter operation to arrive at the total operation and maintenance costs for filter operation. An operation and maintenance summation is presented in Table 68.

## Table 67

## Construction Cost

## Hydraulic Surface Wash Systems

| | Individual Filter Area - ft$^2$ | | | | | |
|---|---|---|---|---|---|---|
| | 70 | 175 | 350 | 700 | 1,000 | 1,275 |
| Manufactured Equipment | $ 4,320 | 2,840 | 8,270 | 7,730 | 11,610 | 17,190 |
| Labor | 620 | 660 | 1,230 | 1,400 | 2,000 | 2,880 |
| Pipe and Valves | 1,210 | 1,200 | 1,650 | 1,260 | 2,170 | 2,560 |
| Electrical and Instrumentation | 6,050 | 4,280 | 4,880 | 3,620 | 4,170 | 4,010 |
| SUBTOTAL | 12,200 | 8,980 | 16,030 | 14,010 | 19,950 | 26,640 |
| Miscellaneous and Contingency | 1,830 | 1,350 | 2,400 | 2,100 | 2,990 | 4,000 |
| TOTAL | $ 14,030 | 10,330 | 18,430 | 16,110 | 22,940 | 30,640 |



**CONSTRUCTION COST**
**HYDRAULIC SURFACE WASH SYSTEMS**

**FIGURE 67**

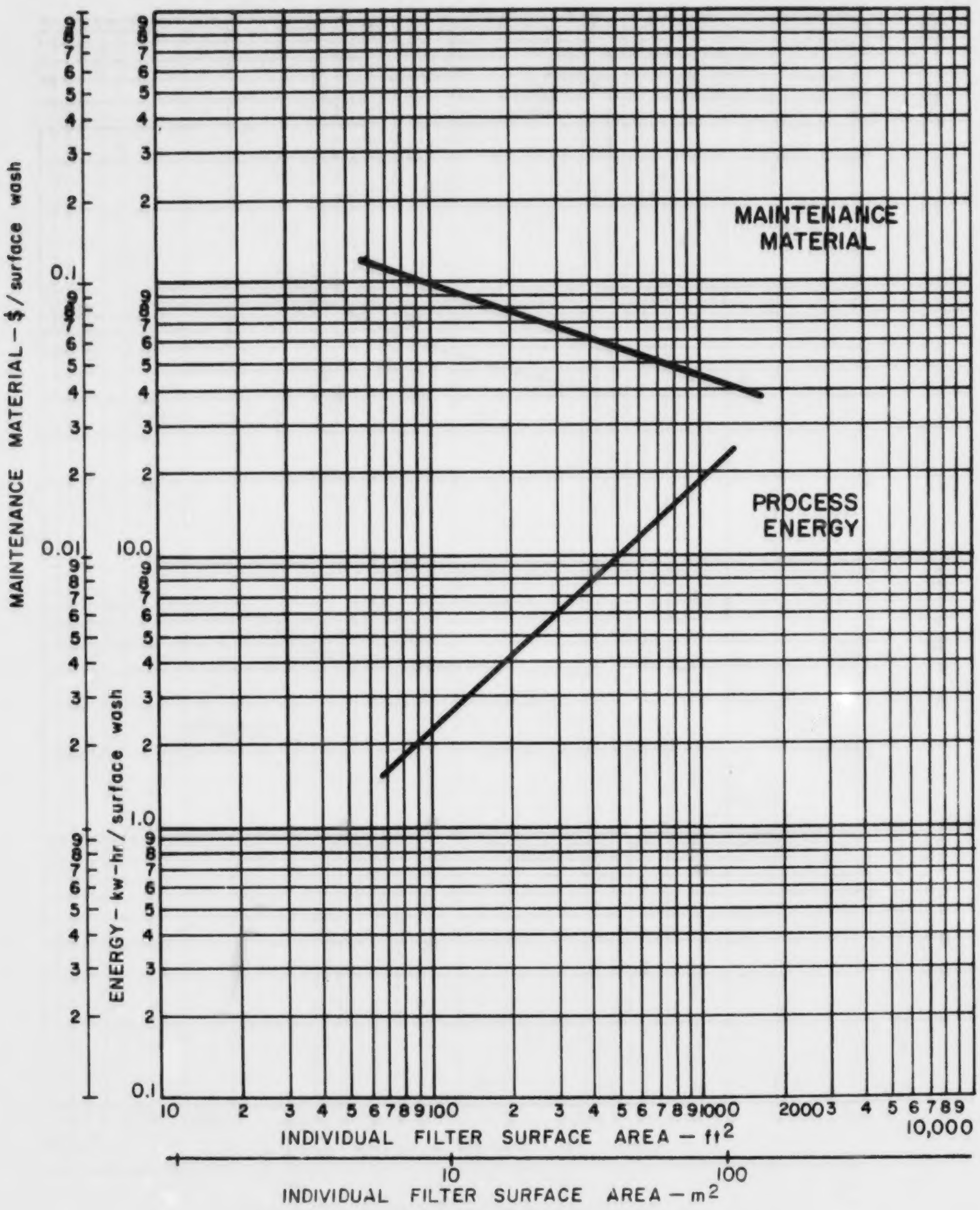
## Table 68

## Operation and Maintenance Summary

## Hydraulic Surface Water Systems

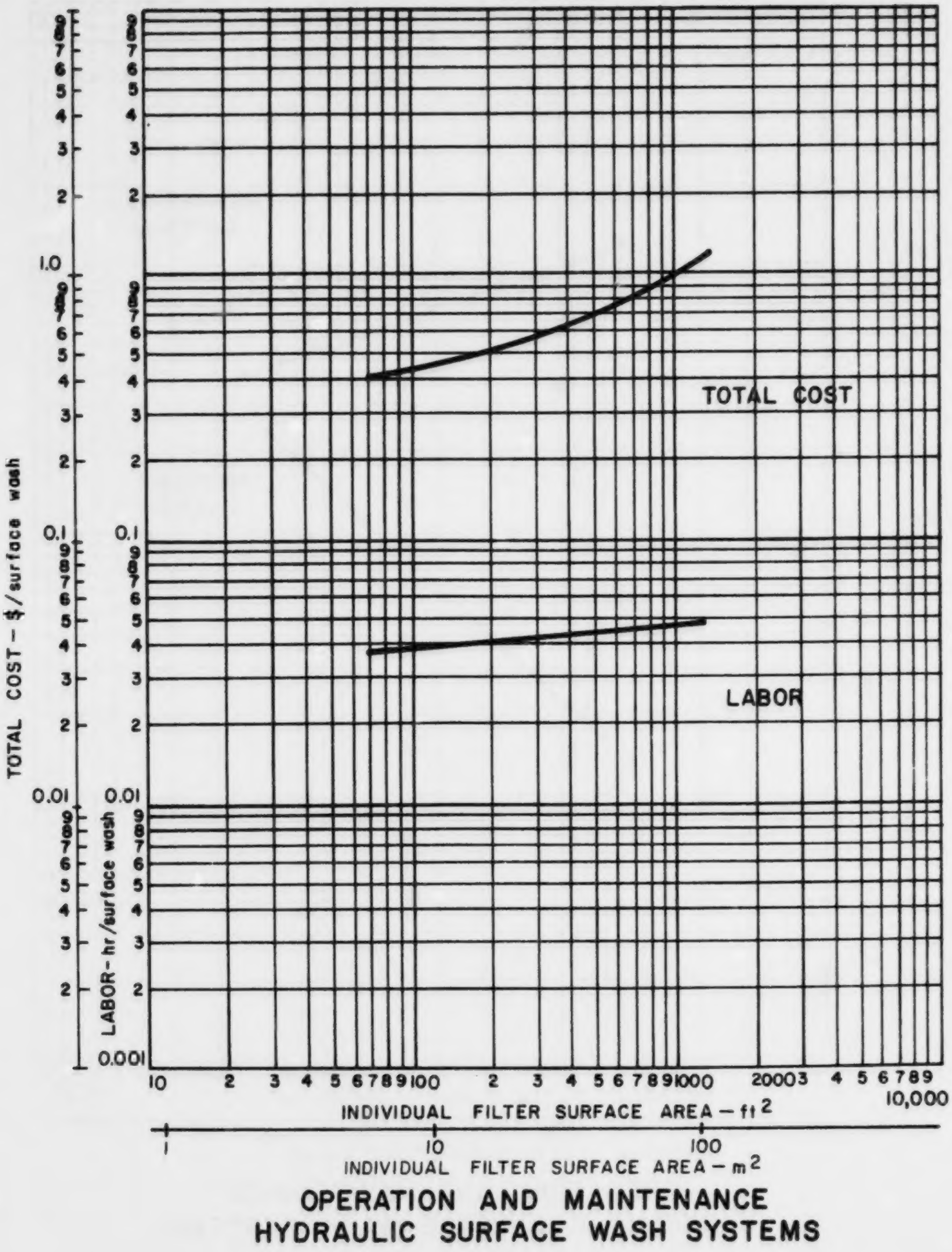
| Individual Filter Surface Area - $ft^2$ | Process Energy-kw-hr/ Surface Wash | Maintenance Material $/Surface Wash | Labor-hours/ Surface Wash | Total Cost* $/Surface Wash |
|---|---|---|---|---|
| 70 | 1.58 | 0.137 | 0.037 | 0.55 |
| 175 | 3.30 | 0.086 | 0.040 | 0.59 |
| 350 | 7.54 | 0.103 | 0.069 | 1.02 |
| 700 | 12.37 | 0.055 | 0.042 | 0.85 |
| 1,000 | 19.81 | 0.049 | 0.039 | 1.03 |
| 1,275 | 24.75 | 0.037 | 0.051 | 1.29 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
HYDRAULIC SURFACE WASH SYSTEMS

FIGURE 68



**OPERATION AND MAINTENANCE**
**HYDRAULIC SURFACE WASH SYSTEMS**

**FIGURE 69**

## CONSTRUCTION COST

### Backwash Pumping Facilities

The cost of the backwash pumping system must be added to the basic cost for the filtration structure, filter media cost, surface wash, and any required backwash water storage capacity to arrive at the filtration facility cost. Included within the backwash pumping system cost is the cost of required pumps and motors, including one standby unit, flow control, filter backwash sequencing control, pump station valving, the backwash header cost not included in the filter structure, and motor starters. Backwash piping and valving was sized for a velocity of 7 feet per second. Housing costs are not included. The assumed pumping head for the backwash pump was 50 feet TDH and the maximum design rate for backwash was 18 gpm/square foot. The maximum size pump utilized was 7,000 gpm and for all installations, one standby pump was included.

Construction cost estimates are shown by cost component in Table 69 and on Figure 70. Costs are presented as a function of backwash pumping capacity, as the rate will vary with the type of media utilized and the size of filters used.

## OPERATION AND MAINTENANCE COST

### Backwash Pumping Facilities

Since backwash frequency is dependent upon raw water quality, and is not a function of filter size, all operation and maintenance curves are presented using a per backwash basis. For dual cell filters, a backwash is defined as a backwash of both cells. Using this approach, variations in water quality and frequency of backwash can be readily taken into account in determining annual cost.

Energy requirements per backwash were calculated using a backwash rate of 15 gpm/square foot, a pumping head of 50 feet TDH, and an overall motor/pump efficiency of 72 percent. Energy requirements per backwash are based on a backwash period of 10 minutes.

Labor requirements are for maintenance labor only as all operation labor is included with the filtration structure curves. To convert annual labor requirements to labor per backwash, two backwashes per day per filter were assumed.

Maintenance material costs are for repair of the backwash pumps, the motor starters, and valving. Costs are expressed per backwash assuming two backwashes per day.

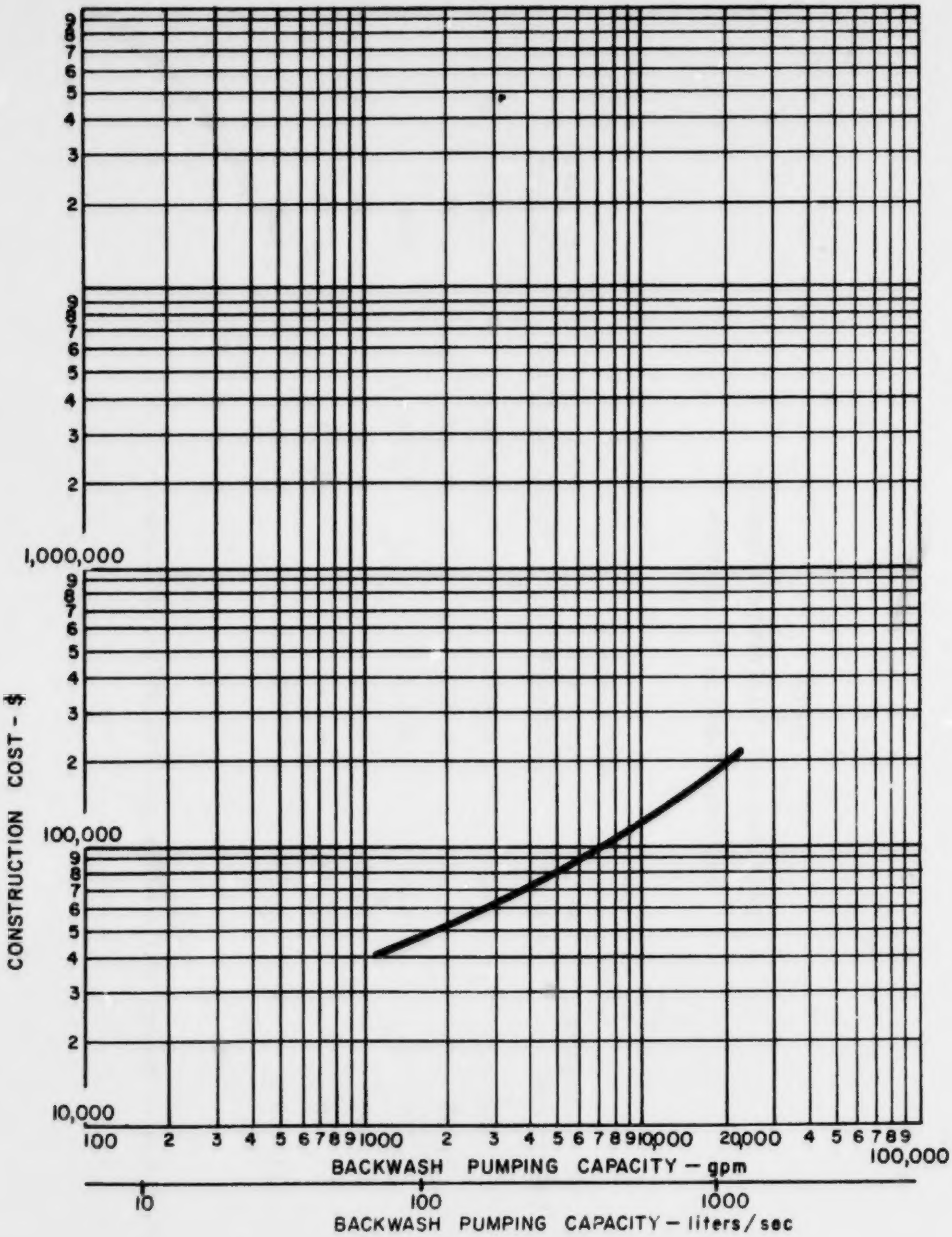
Figures 71 and 72 present the operation and maintenance requirements which are also summarized in Table 70. The total cost curve is based upon a 10 minute backwash at 15 gpm/square foot, and a 50 TDH. If different conditions are utilized, the total cost should be adjusted accordingly.

## Table 69

## Construction Cost

## Backwash Pumping Facilities

|  | Pumping Capacity |  |  |  |  |
|---|---|---|---|---|---|
| GPM | 1,260 | 3,150 | 6,300 | 18,000 | 22,950 |
| MGD | 1.8 | 4.5 | 9.1 | 25.9 | 33 |
| Manufactured Equipment | $ 10,750 | 13,760 | 36,180 | 72,370 | 90,460 |
| Labor | 2,900 | 4,200 | 4,640 | 8,840 | 11,840 |
| Pipe and Valves | 9,200 | 16,640 | 16,640 | 31,410 | 42,130 |
| Electrical and Instrumentation | 12,750 | 15,320 | 15,990 | 26,810 | 31,760 |
| SUBTOTAL | 35,600 | 49,920 | 73,400 | 139,430 | 176,190 |
| Miscellaneous and Contingency | 5,340 | 7,490 | 11,010 | 20,910 | 26,430 |
| TOTAL | $ 40,940 | 57,410 | 84,410 | 160,340 | 202,620 |



CONSTRUCTION COST
BACKWASH PUMPING FACILITIES

FIGURE 70

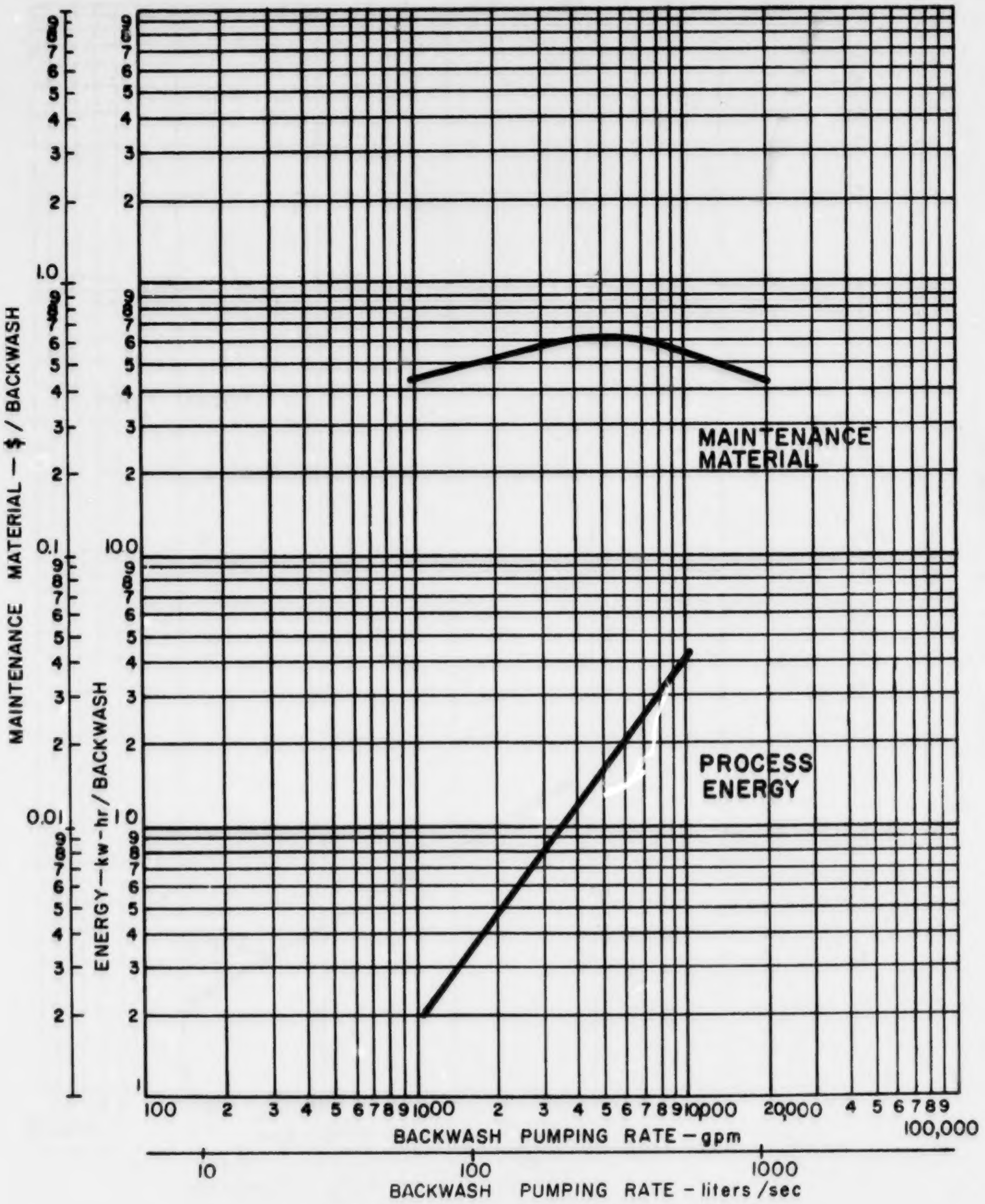
## Table 70

## Operation and Maintenance Summary

## Backwash Pumping Facilities

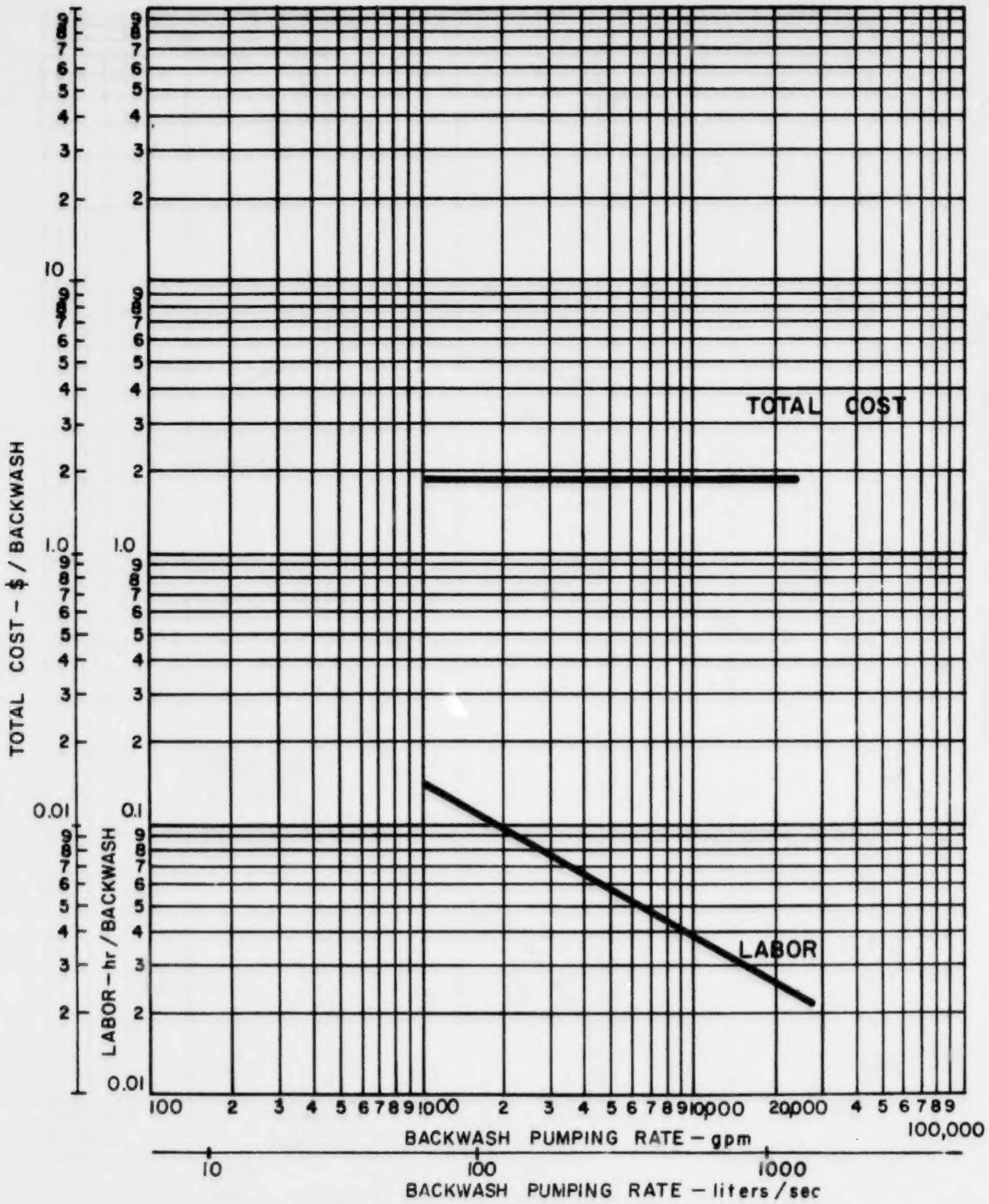
| Backwash Pumping Rate - gpm | Process Energy kw-hr/ Backwash | Maintenance Material $/Backwash | Labor Hours/Backwash | Total Cost* $/Backwash |
|---|---|---|---|---|
| 1,050 | 2.29 | 0.479 | 0.130 | 1.85 |
| 2,625 | 5.73 | 0.377 | 0.072 | 1.27 |
| 5,250 | 11.46 | 0.616 | 0.086 | 1.82 |
| 10,500 | 22.91 | 0.466 | 0.041 | 1.56 |
| 15,000 | 32.73 | 0.411 | 0.034 | 1.73 |
| 19,125 | 41.73 | 0.355 | 0.023 | 1.84 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
BACKWASH PUMPING FACILITIES

FIGURE 71



OPERATION AND MAINTENANCE
BACKWASH PUMPING FACILITIES

FIGURE 72

## CONSTRUCTION COST

### Reverse Osmosis

Reverse osmosis utilizes membranes to remove a high percentage of almost all inorganic ions, turbidity, bacteria, and viruses. Most organic matter is also removed, with the exception of several materials, including most halogenated and low molecular weight compounds.

Figures 73 and 74 present costs for construction of complete reverse osmosis plants in the size ranges from 2,500 gpd to 1 mgd and from 1 mgd to 200 mgd, respectively. Commercial units are available in sizes up to about 5,000 gpd for the membrane elements and up to 30,000 gpd for the reverse osmosis modules (pressure vessels); therefore large scale plants would be composed of many smaller, parallel modules. Components taken into account in the construction cost estimates including housing, structural steel and miscellaneous metalwork, tanks, piping, valves, pumps, reverse osmosis membrane elements and pressure vessels, flow meters, cartridge filters, acid and polyphosphate feed equipment and also cleaning equipment. The cost curves are based upon the use of either spiral wound or hollow fine fiber reverse osmosis membranes. Table 71 presents the breakdown of construction costs.

The efficiency of the membrane elements in reverse osmosis systems may be impaired by scaling, due to slightly soluble or insoluble compounds, or by fouling, due to the deposition of colloidal or suspended materials. Because of this, a very important consideration in the design of a reverse osmosis system is the provision of adequate pretreatment to protect the membrane from excessive scaling and fouling and to avoid frequent cleaning requirements. In the development of the cost curves, adequate pretreatment was assumed to precede the reverse osmosis process, and costs for pretreatment are not included in the estimates.

The construction cost curve applies to waters with a total dissolved solids (TDS) concentration ranging up to about 10,000 mg/l. Other considerations, such as calcium sulfate and silica concentrations and also the desired water recovery, affect costs more than the influent TDS concentration. The temperature of the feedwater is assumed to be between 65 and 95 degrees Fahrenheit, while the pH of the feedwater is adjusted to near 5.5 - 6.0 prior to the reverse osmosis process. A single-pass treatment system (only one pass through the membrane) is assumed, with an operating pressure of 400 - 450 psi. The assumed water recoveries for different flow ranges are as follows:

| Flow Range | Water Recovery - % |
|---|---|
| 2,500 - 10,000 gpd | 60 |
| 10,000 - 100,000 gpd | 70 |
| 100,000 gpd - 1.0 mgd | 75 |
| 1.0 - 10 mgd | 80 |
| 10 - 200 mgd | 85 |

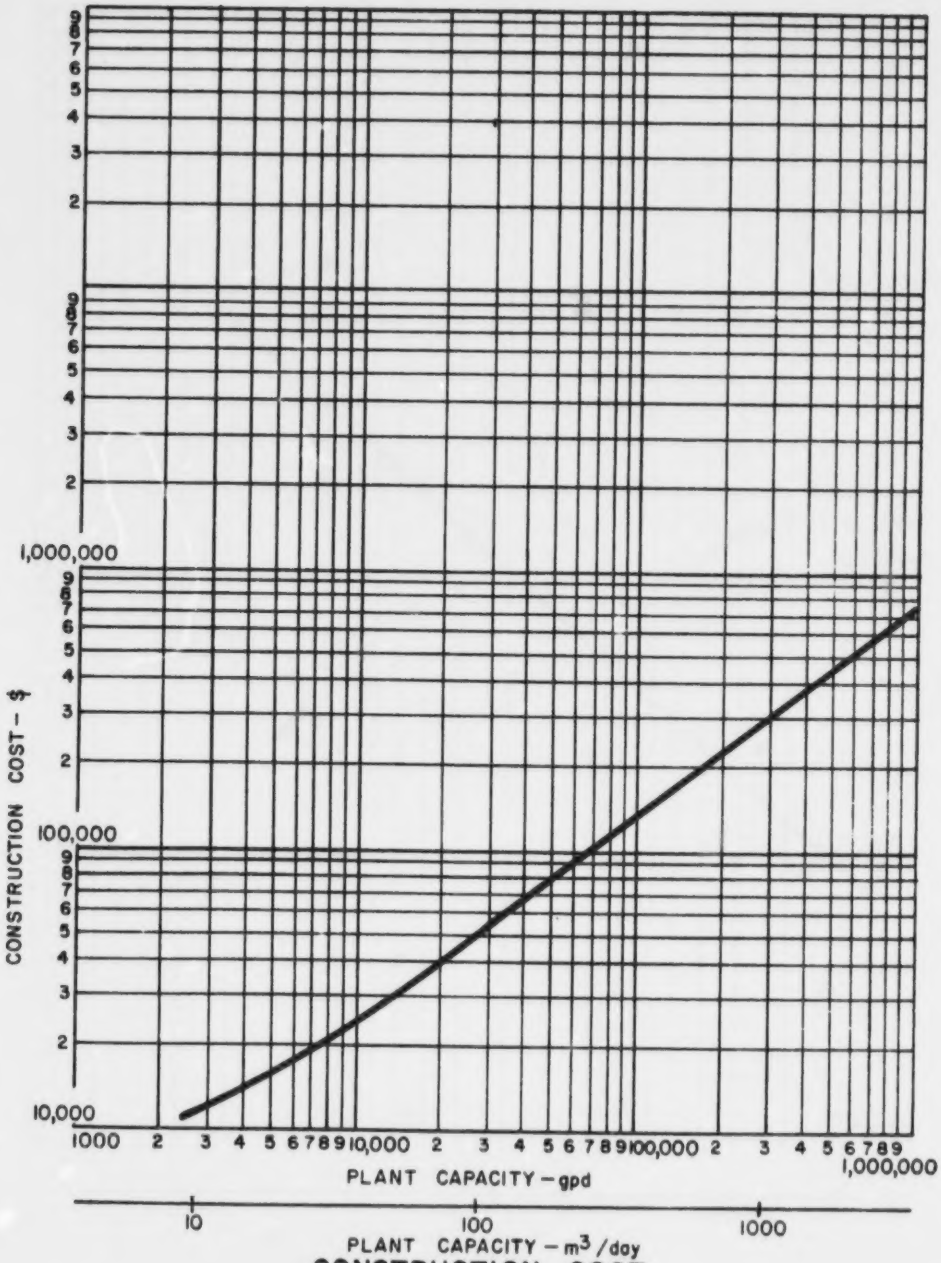
Brine disposal costs are not included in the estimates.

# Table 71

# Construction Cost

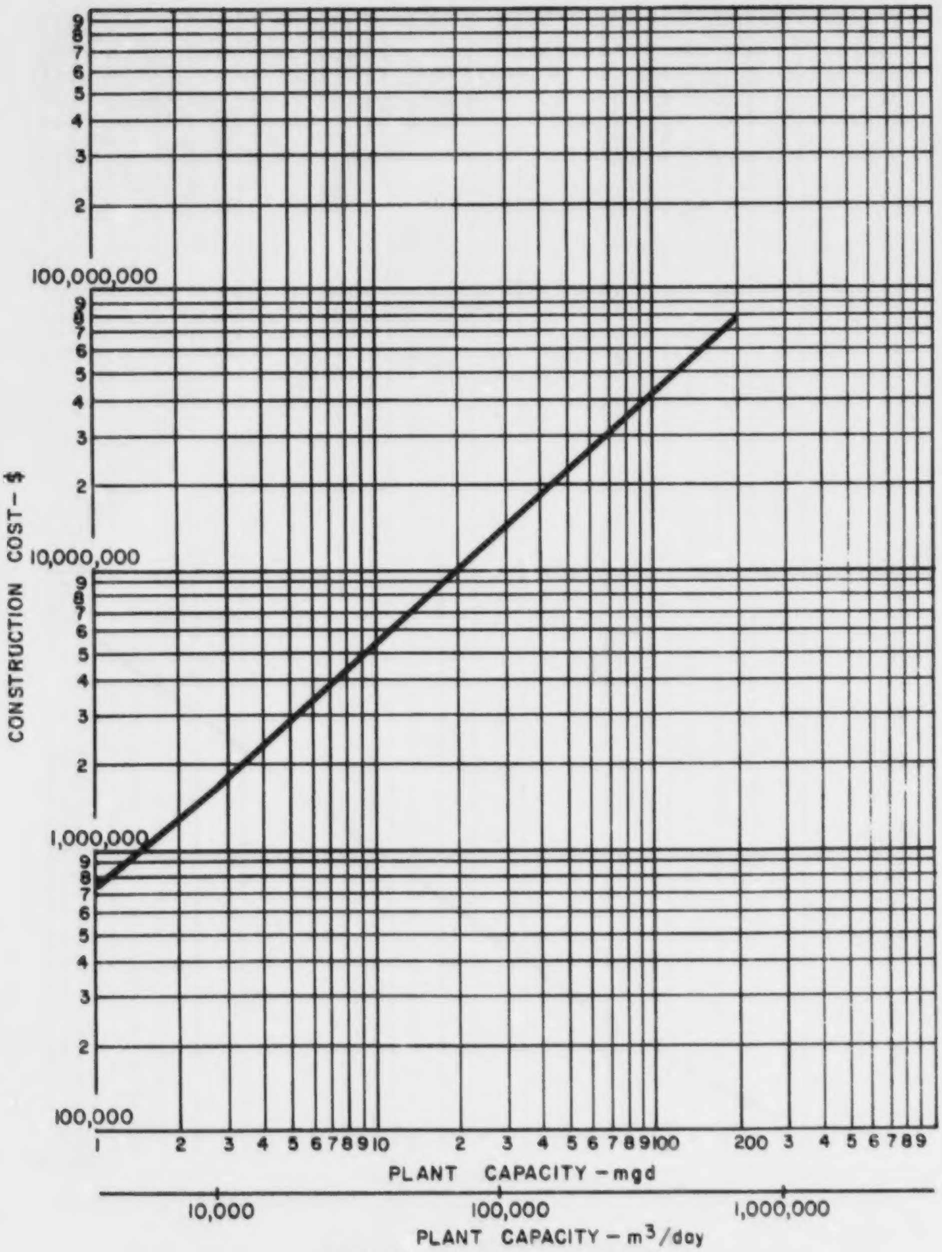
# Reverse Osmosis

| | Plant Capacity - mgd | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0025 | 0.01 | 0.1 | 1.0 | 10 | 100 | 200 |
| Manufactured Equipment | $ 3,500 | 10,500 | 76,400 | 447,000 | 3,260,000 | 27,500,000 | 53,200,000 |
| Labor | 730 | 2,100 | 15,300 | 67,000 | 330,000 | 2,200,000 | 2,700,000 |
| Electrical and Instrumentation | 4,000 | 4,500 | 10,200 | 62,800 | 464,500 | 3,472,900 | 6,636,400 |
| Housing | 2,500 | 3,800 | 6,000 | 60,000 | 432,000 | 2,250,000 | 3,900,000 |
| SUBTOTAL | 10,730 | 20,900 | 107,900 | 636,800 | 4,486,500 | 35,422,900 | 66,436,400 |
| Miscellaneous and Contingency | 1,610 | 3,140 | 16,190 | 95,520 | 672,980 | 5,313,440 | 9,965,460 |
| TOTAL | 12,340 | 24,040 | 124,090 | 732,320 | 5,159,480 | 40,736,340 | 76,401,860 |



CONSTRUCTION COST
REVERSE OSMOSIS

FIGURE 73



CONSTRUCTION COST
REVERSE OSMOSIS

FIGURE 74

## OPERATION AND MAINTENANCE COST

### Reverse Osmosis

Electrical energy usage is included for the high pressure feedwater pumps, based on an operating pressure of 450 psi and on the water recoveries listed in the construction cost write-up. For other pumps and chemical feed equipment, an energy usage of 10 percent of the usage for the high pressure pumps was assumed. Electrical energy for lighting, heating, and ventilating was calculated, based on an estimated floor area required for complete housing of the reverse osmosis equipment.

The largest maintenance material requirement is for membrane replacement; a membrane life of three years was used in the cost estimates. Other maintenance material requirements are for replacement of cartridge filters, for membrane cleaning chemicals, and for materials needed for periodic repair of pumps, motors, and electrical control equipment. The maintenance material costs vary from 17.5 cents per thousand gallons for plants above 10 mgd to 25 cents per thousand gallons for plants below 1 mgd. Costs for pretreatment chemicals, such as acid and polyphosphate, are not included in the estimates. The chemicals utilized and the dosages required will show great variability between different water supplies, and should be determined from pilot plant testing.

Labor requirements are for cleaning and replacing membranes, replacing cartridge filters, maintaining the high pressure and other pumps, preparing treatment chemicals and determining proper dosages, maintaining chemical feed equipment, and monitoring performance of the reverse osmosis membranes. Membrane cleaning was assumed to occur monthly. In estimating labor requirements a minimum of about one and one half hours per day of labor was assumed for the smallest plant.

Operation and maintenance requirements are summarized in Table 72 and illustrated in Figures 75 to 78.

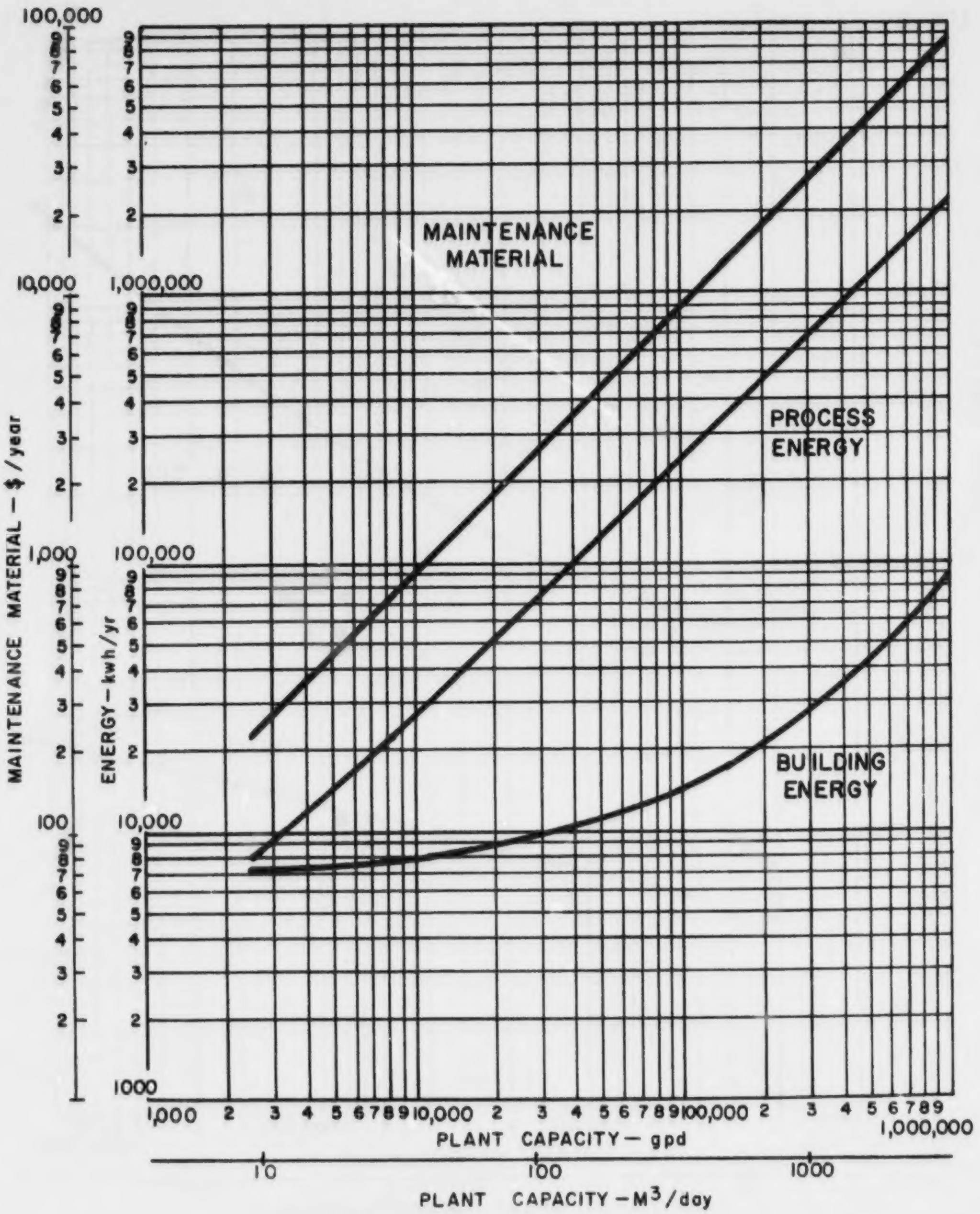
## Table 72

### Operation and Maintenance Summary

### Reverse Osmosis

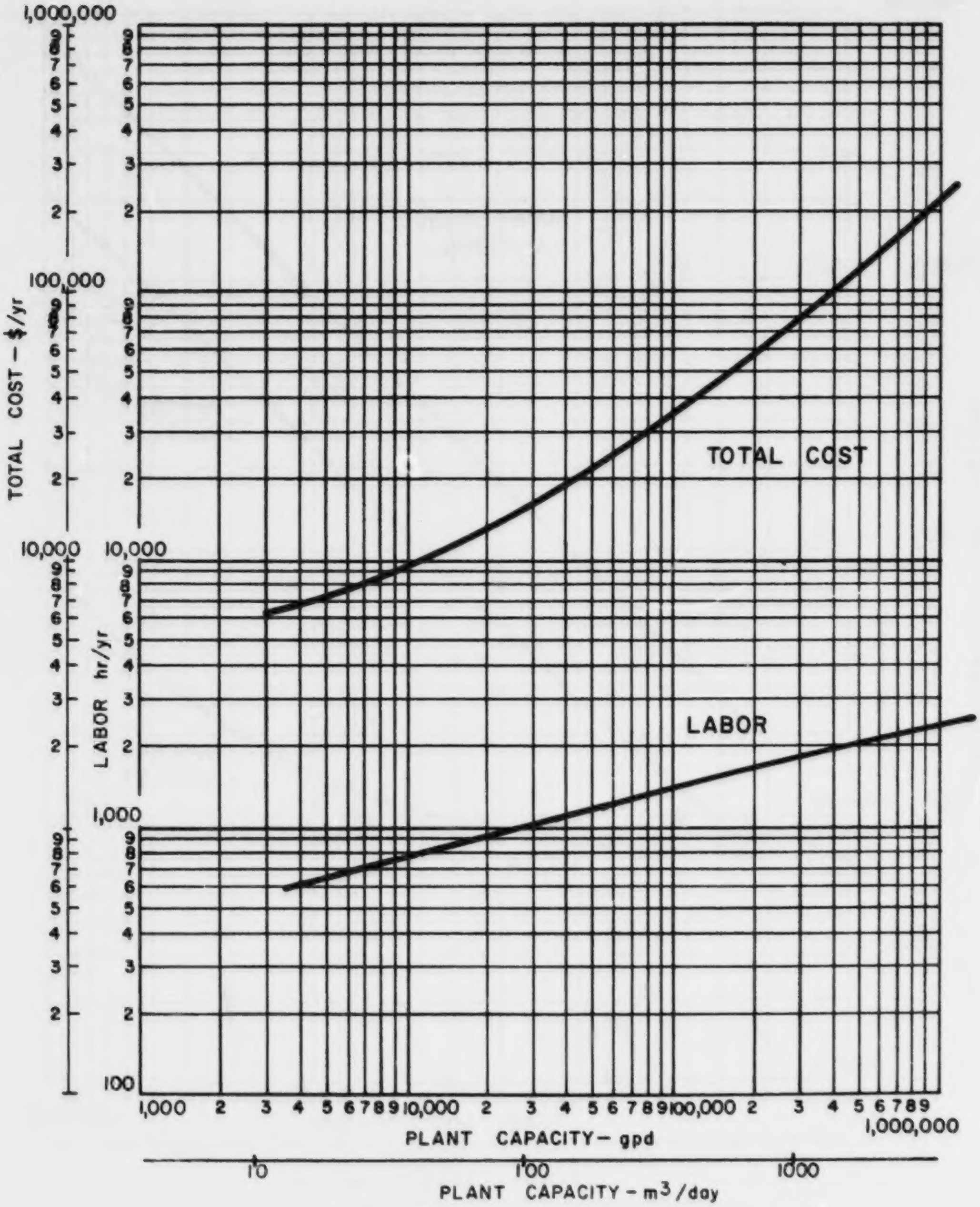
| Plant Capacity mgd | Energy kwh/yr Building | Energy kwh/yr Process | Energy kwh/yr Total | Maintenance Material - $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 0.0025 | 7,000 | 8,030 | 15,030 | 230 | 510 | 5,780 |
| 0.01 | 10,500 | 28,100 | 38,600 | 910 | 710 | 9,170 |
| 0.1 | 15,400 | 260,980 | 276,380 | 9,100 | 1,320 | 30,590 |
| 1.0 | 105,400 | 2,409,000 | 2,514,000 | 91,000 | 1,840 | 184,820 |
| 10 | 840,000 | 22,082,500 | 22,922,500 | 700,000 | 2,840 | 1,416,080 |
| 100 | 7,560,000 | 220,825,000 | 228,385,000 | 6,390,000 | 6,670 | 13,308,250 |
| 200 | 15,120,000 | 441,650,000 | 456,770,000 | 12,800,000 | 11,550 | 26,618,600 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



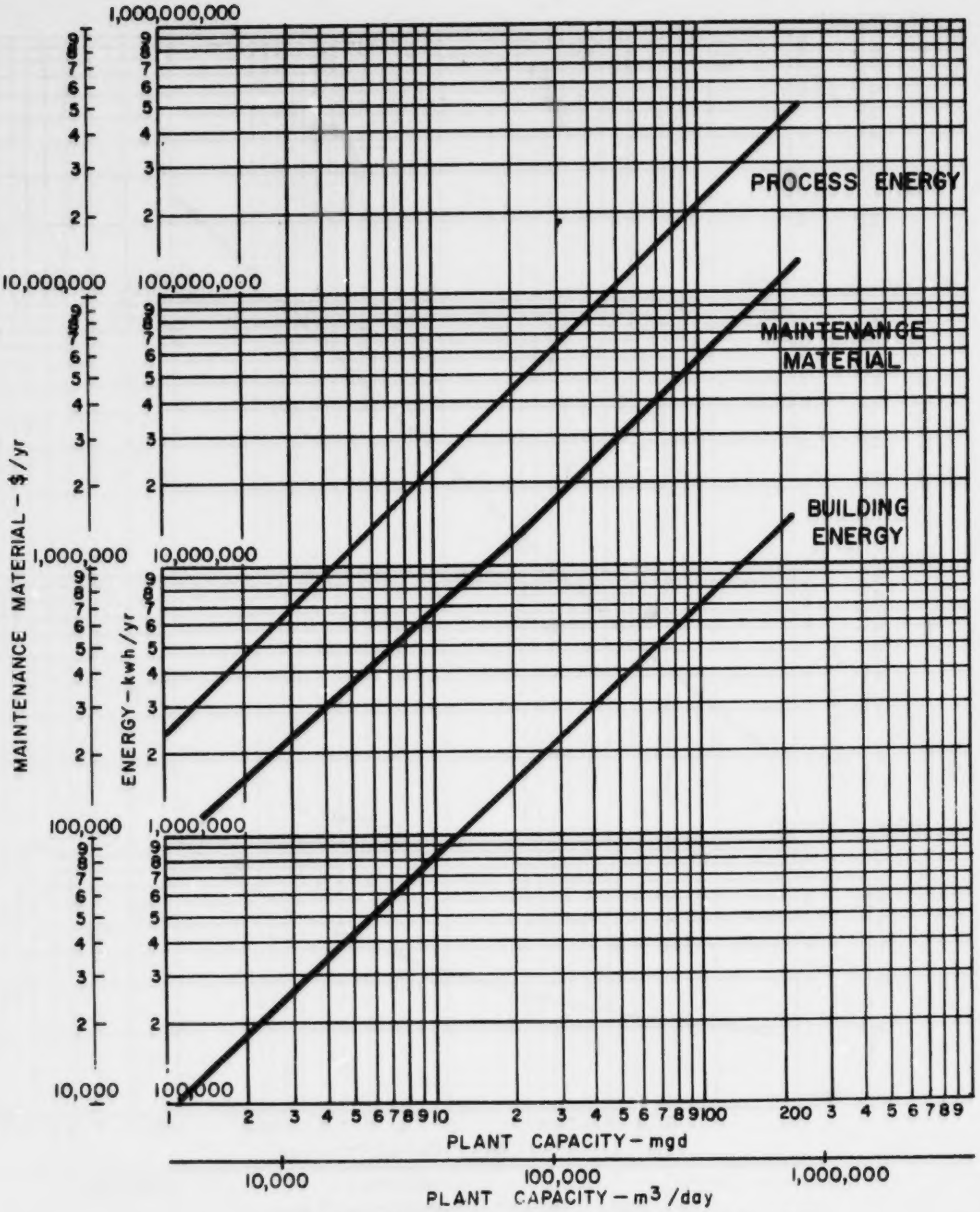
OPERATION AND MAINTENANCE
REVERSE OSMOSIS

FIGURE 75



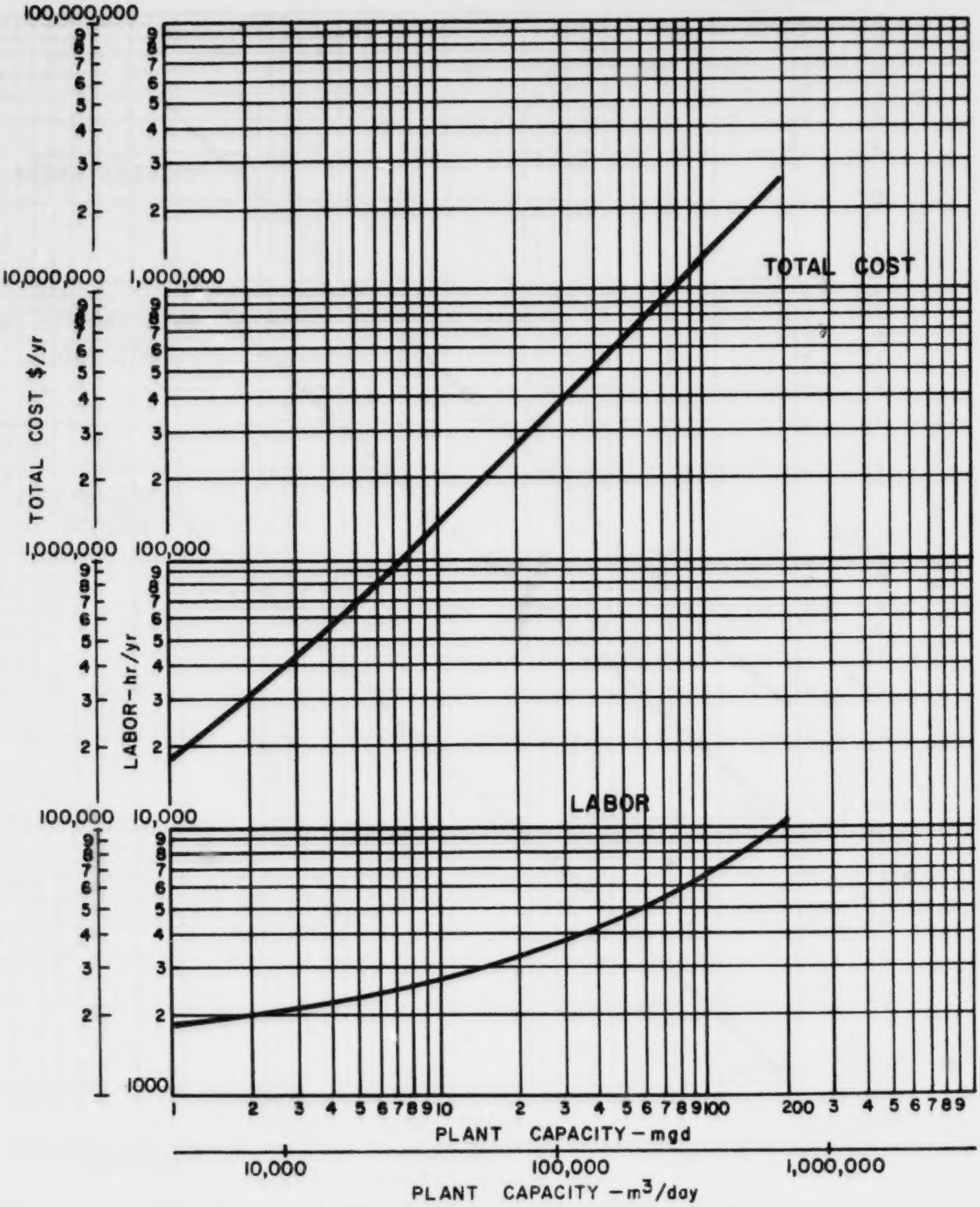
OPERATION AND MAINTENANCE
REVERSE OSMOSIS

FIGURE 76



OPERATION AND MAINTENANCE
REVERSE OSMOSIS

FIGURE 77



## OPERATION AND MAINTENANCE REVERSE OSMOSIS

FIGURE 78

## CONSTRUCTION COST

### Ion Exchange - Softening

Cation exchange resins can be utilized for the removal of not only hardness, but also other constituents such as barium, trivalent chromium, lead, manganese, mercury and radium. Pressure units are generally competitive with gravity units at low capacities, while gravity units are more economical at higher flows. An advantage of pressurized exchange units is the capability of pumping through the softener and directly to the clearwell, or other point, possibly eliminating the need for double pumping.

Facilities were sized based upon an exchange capacity of 20 kilograins per cubic foot and a hardness reduction of 300 mg/l. Regeneration facilities were sized on the basis of 150 bed volumes treated prior to regeneration and a regenerant requirement of 0.275 pounds of sodium chloride per kilograin of exchange capacity. The total regeneration time required is 50 minutes. Of this time, 10 minutes is for backwash, 20 minutes is regeneration brine contact time (brining and displacement rinse), and 20 minutes is a fast rinse at 1.5 gpm/ft$^3$. Feedwater was assumed to be of sufficient clarity to require backwashing only for resin reclassification. Backwash pumping facilities and media installation are included in the construction cost. In place resin costs of $45.00 per cubic foot were utilized.

No facilities are included in the construction cost for spent brine disposal.

### Pressure Ion Exchange Softening

Construction costs were developed for pressure ion exchange using the conceptual information presented in Table 73. The contact vessels are fabricated steel, with a baked phenolic lining added after fabrication, and constructed for 100 psi working pressure. The depth of resin was 6 feet, and the contact vessel was designed to allow for as much as 80 percent media expansion during backwash. A gravel layer between underdrains and media was not included.

Regeneration facilities include two salt storage/brining basins, which are open, reinforced concrete structures, constructed with the top foot above ground level. Saturated brine withdrawal from the salt storage/brining basins is 26 percent by weight. A saturated brine storage of two and a half days normal use was provided in the storage/brining basins. Pumping facilities were included to pump from the brining tanks to the contact vessels. An eductor is utilized to add sufficient water to dilute the brine to a 10 percent concentration as it is being transferred from the salt storage/brining tank to the contact vessel.

Construction costs for pressure ion exchange softening are presented in Figure 79 and summarized in Table 74.

## Table 73

## Conceptual Design

## Pressure Ion Exchange Softening

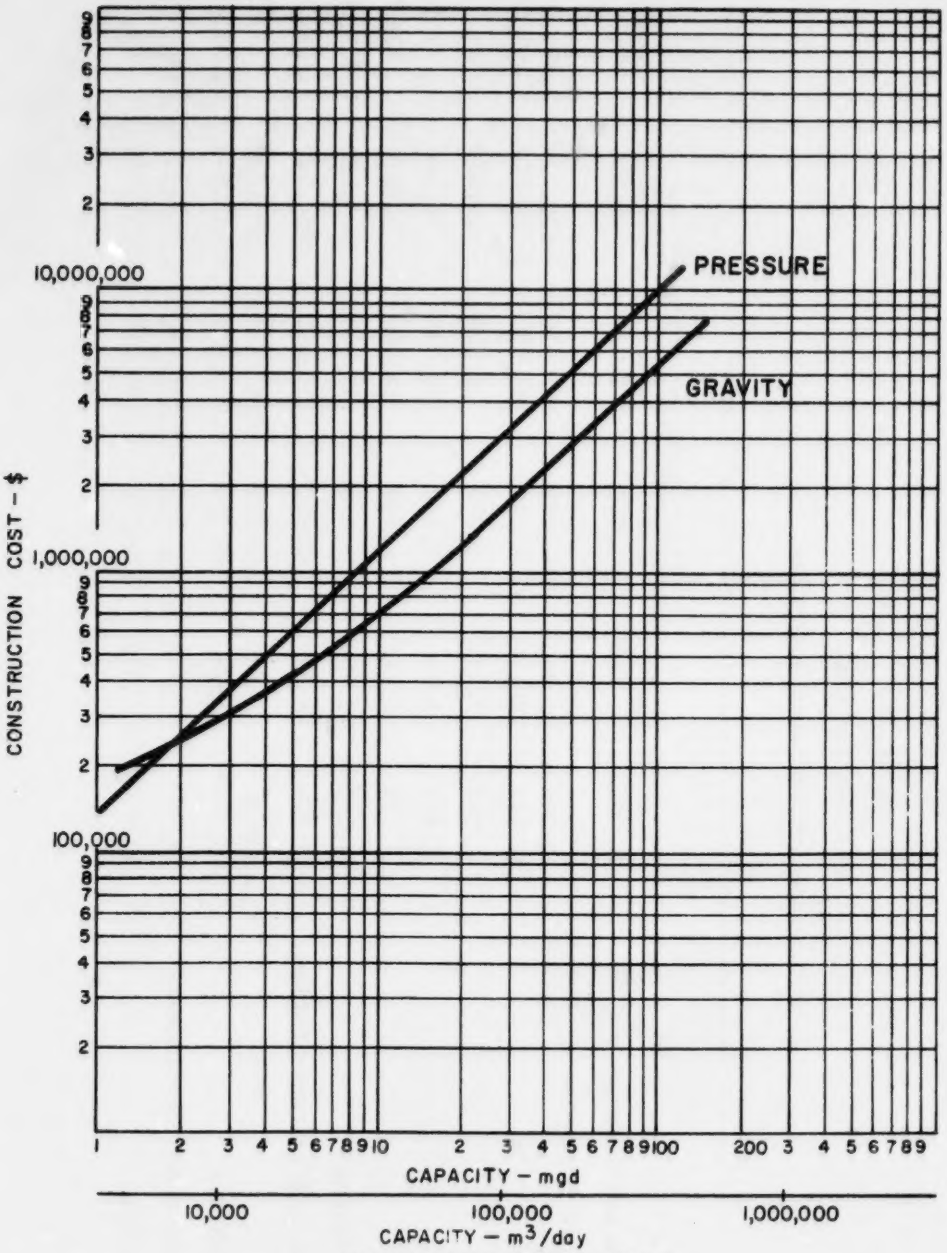
| Plant Capacity - mgd | Number of Contactors | Diameter of Contactors -ft | $ft^2$ of Housing | Total Salt Storage - Brining Capacity - $ft^3$ |
|---|---|---|---|---|
| 1.1 | 2 | 8 | 558 | 918 |
| 3.7 | 3 | 12 | 1,232 | 3,146 |
| 6.1 | 5 | 12 | 1,980 | 5,244 |
| 12.3 | 10 | 12 | 3,960 | 10,488 |
| 49 | 40 | 12 | 15,840 | 41,954 |
| 122.6 | 100 | 12 | 31,680 | 104,890 |

## Table 74

## Construction Cost

## Pressure Ion Exchange Softening

| | Plant Capacity - mgd | | | | | |
|---|---|---|---|---|---|---|
| | 1.1 | 3.7 | 6.1 | 12.3 | 49.0 | 122.6 |
| Excavation and Sitework | $ 390 | 780 | 1,040 | 2,080 | 4,270 | 8,770 |
| Manufactured Equipment | | | | | | |
| Equipment | 23,400 | 61,460 | 104,090 | 207,520 | 830,220 | 2,075,800 |
| Resin | 27,140 | 91,610 | 152,690 | 305,380 | 1,221,480 | 3,053,700 |
| Concrete | 1,260 | 2,490 | 3,310 | 6,620 | 13,080 | 26,280 |
| Steel | 1,930 | 3,790 | 5,010 | 10,020 | 19,660 | 39,510 |
| Labor | 2,520 | 4,910 | 6,480 | 12,960 | 24,370 | 47,830 |
| Pipe and Valves | 14,240 | 40,650 | 77,970 | 155,940 | 623,760 | 1,333,680 |
| Electrical and Instrumentation | 31,700 | 46,500 | 77,900 | 183,600 | 684,500 | 1,738,300 |
| Housing | 18,000 | 32,750 | 58,100 | 105,750 | 364,350 | 713,000 |
| SUBTOTAL | 120,580 | 284,940 | 486,590 | 989,870 | 3,785,690 | 9,036,870 |
| Miscellaneous and Contingency | 18,090 | 42,740 | 72,990 | 148,480 | 567,850 | 1,355,530 |
| TOTAL | $ 138,670 | 327,680 | 559,580 | 1,138,350 | 4,353,540 | 10,392,400 |



CONSTRUCTION COST
ION EXCHANGE - SOFTENING

FIGURE 79

## Gravity Ion Exchange - Softening

Construction costs were developed for gravity ion exchange, using the conceptual designs presented in Table 75. The structures are similar to those used for gravity filtration. Differences from gravity filter structures are larger influent channels to allow a higher loading per square foot of surface area and use of an eighteen foot wall depth to allow a loading of 8 gpm/ft$^2$. A six foot resin depth was utilized and underdrains not requiring an overlying gravel layer were utilized. Piping was modified from gravity filtration by the addition of a regenerant line. Facilities included for regenerant storage and dilution to 10 percent were similar to those described for pressure ion exchange.

Construction costs for gravity ion exchange softening are presented in Figure 79 and in Table 76.

## OPERATION AND MAINTENANCE COST

## Ion Exchange - Softening

Electrical requirements are for regenerant pumping, rinse pumping, backwash pumping, and building heating, lighting, and ventilation. Backwash pumping was based upon a ten minute wash period at 8 gpm/ft$^2$. Regenerant pumping was based upon a regenerant rate of 0.7 gallons/minute/cubic foot of resin and a regeneration time of 20 minutes. Fast rinse pumping was based upon a 20 minute rinse at a rate of 30 gallons per cubic foot of media. All pumping was assumed to be against a 25 foot TDH. Feed water pumping costs are not included.

Maintenance material costs for periodic repair and replacement of components were estimated based on one percent of the construction cost. Resin replacement costs are for resin lost annually by physical attrition as well as loss of capacity due to chemical fouling. A 3 percent annual loss of resin capacity due to physical and chemical causes is typical for cation resins. In addition, the resin must be completely replaced every 8-10 years. To account for this loss of resin and the required replacement every 8 to 10 years, an annual cost equivalent to 13 percent of the resin cost is also included in the maintenance material. No costs are included for regenerant.

Labor requirements are for operation and maintenance of the ion exchange vessels and the pumping facilities. Hours were estimated based upon comparable size filtration plants and filter pumping facilities. Labor requirements are also included for periodic media addition and replacement of the media every 8 to 10 years.

No costs are included for spent brine disposal. Operation and maintenance costs are presented in Figures 80 to 83 and are summarized in Tables 77 and 78 for pressure and gravity ion exchange softening.

## Table 75

## Conceptual Designs

## Gravity Ion Exchange Softening

| Plant Capacity - mgd | Number of Beds | $Ft^2$/Bed | $Ft^2$ of Housing | Total Salt Storage and Primary Capacity $Ft^3$ |
|---|---|---|---|---|
| 1.5 | 2 | 70 | 150 | 1,300 |
| 7.5 | 4 | 175 | 420 | 6,490 |
| 15 | 4 | 350 | 800 | 12,990 |
| 75 | 10 | 700 | 2,900 | 64,930 |
| 150 | 14 | 1,000 | 4,060 | 129,850 |

## Table 76

## Construction Cost

## Gravity Ion Exchange Softening

| | Plant Flow Rate - mgd | | | | |
|---|---|---|---|---|---|
| | 1.5 | 7.5 | 15 | 75 | 150 |
| Excavation and Sitework | $ 3,490 | 6,180 | 9,250 | 31,630 | 55,110 |
| Manufactured Equipment | | | | | |
| Equipment | 40,960 | 88,490 | 137,770 | 527,120 | 960,040 |
| Resin | 37,800 | 189,200 | 378,000 | 1,890,000 | 3,780,000 |
| Concrete | 8,750 | 20,110 | 30,570 | 98,330 | 131,410 |
| Steel | 8,460 | 16,420 | 23,310 | 83,630 | 145,350 |
| Labor | 21,300 | 55,260 | 77,300 | 284,700 | 486,510 |
| Pipe and Valves | 21,770 | 61,050 | 84,060 | 246,710 | 370,190 |
| Electrical and Instrumentation | 19,190 | 55,040 | 55,040 | 142,050 | 241,920 |
| Housing | 16,250 | 37,800 | 65,910 | 272,600 | 480,250 |
| SUBTOTAL | 177,970 | 529,550 | 861,210 | 3,576,770 | 6,650,780 |
| Miscellaneous and Contingency | 26,700 | 79,430 | 129,180 | 536,520 | 997,620 |
| TOTAL | $ 204,670 | 608,980 | 990,390 | 4,113,290 | 7,648,400 |

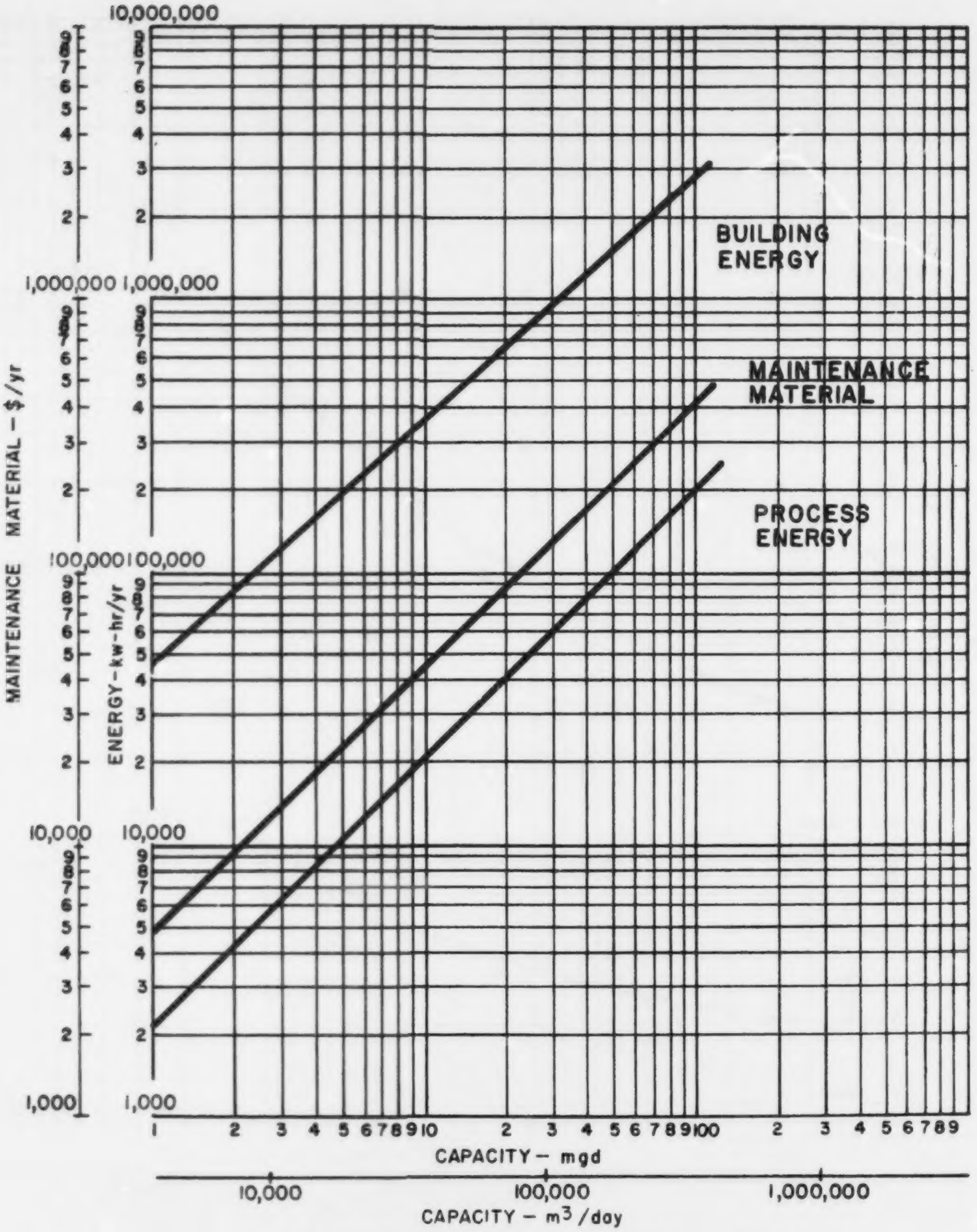
## Table 77

## Operation and Maintenance Summary

## Pressure Ion Exchange Softening

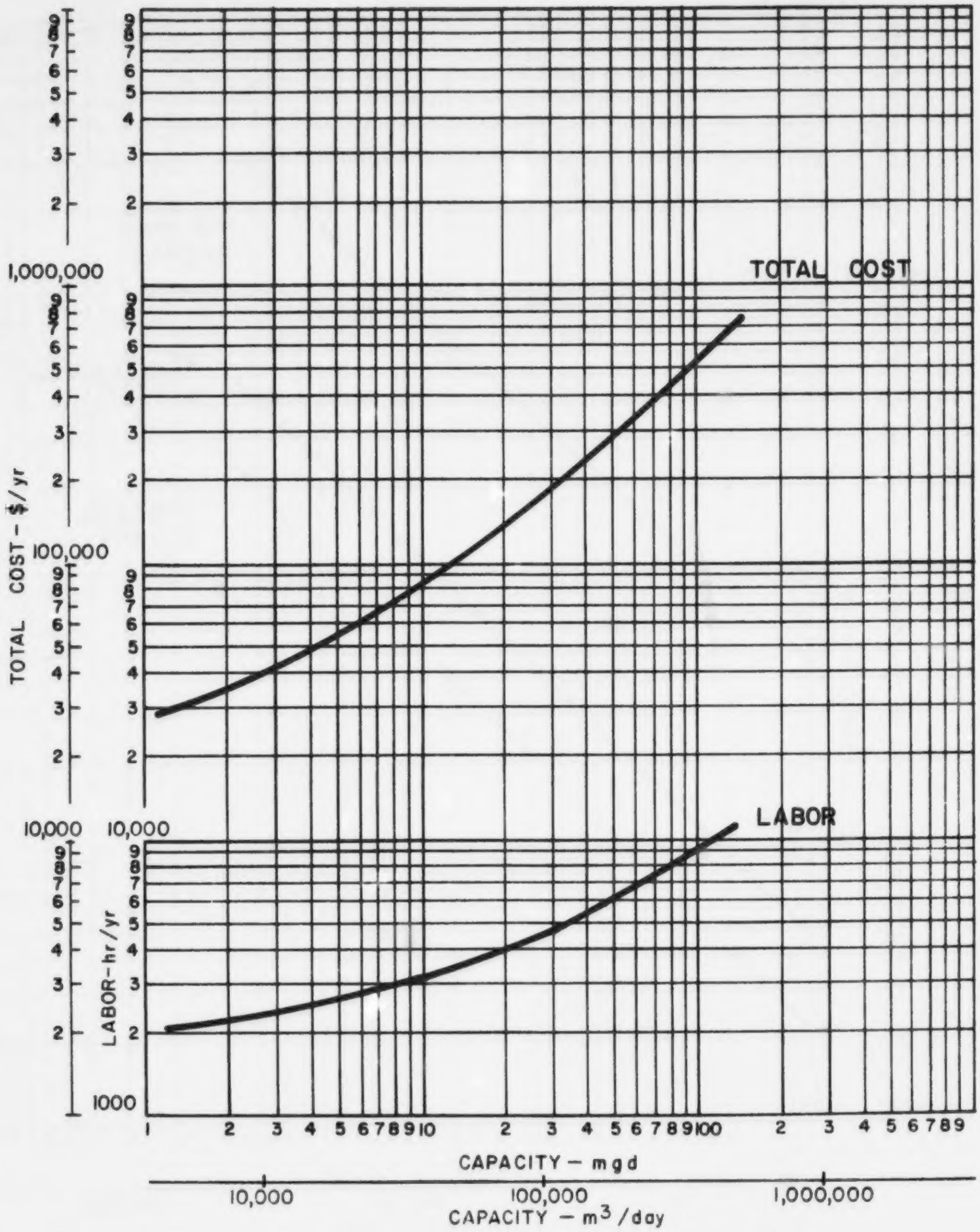
| Plant Flow Rate - mgd | Energy kw-hr/yr Building | Energy kw-hr/yr Process | Energy kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 1.1 | 57,250 | 2,270 | 59,520 | 4,690 | 2,160 | 28,000 |
| 3.7 | 126,400 | 7,620 | 134,020 | 15,140 | 2,700 | 46,160 |
| 6.1 | 203,150 | 12,570 | 215,720 | 25,040 | 3,000 | 61,510 |
| 12.3 | 406,300 | 25,350 | 431,650 | 49,820 | 3,400 | 96,770 |
| 49 | 1,625,180 | 100,970 | 1,726,150 | 197,890 | 6,900 | 318,670 |
| 122.6 | 3,250,370 | 252,630 | 3,503,000 | 489,280 | 13,600 | 730,370 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
PRESSURE ION EXCHANGE SOFTENING

FIGURE 80



**OPERATION AND MAINTENANCE**
**PRESSURE ION EXCHANGE SOFTENING**

FIGURE 81

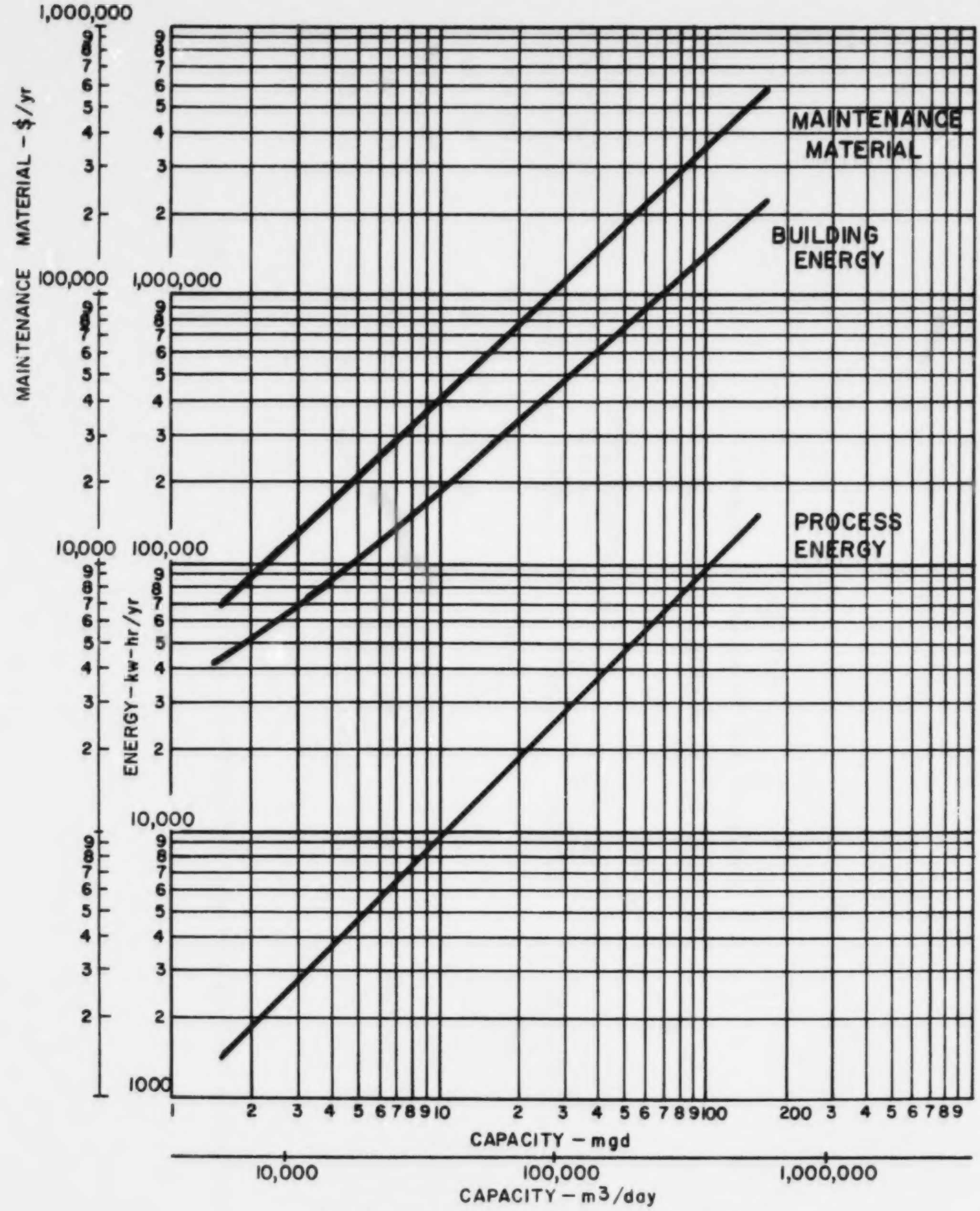
## Table 78

## Operation and Maintenance Summary

## Gravity Ion Exchange Softening

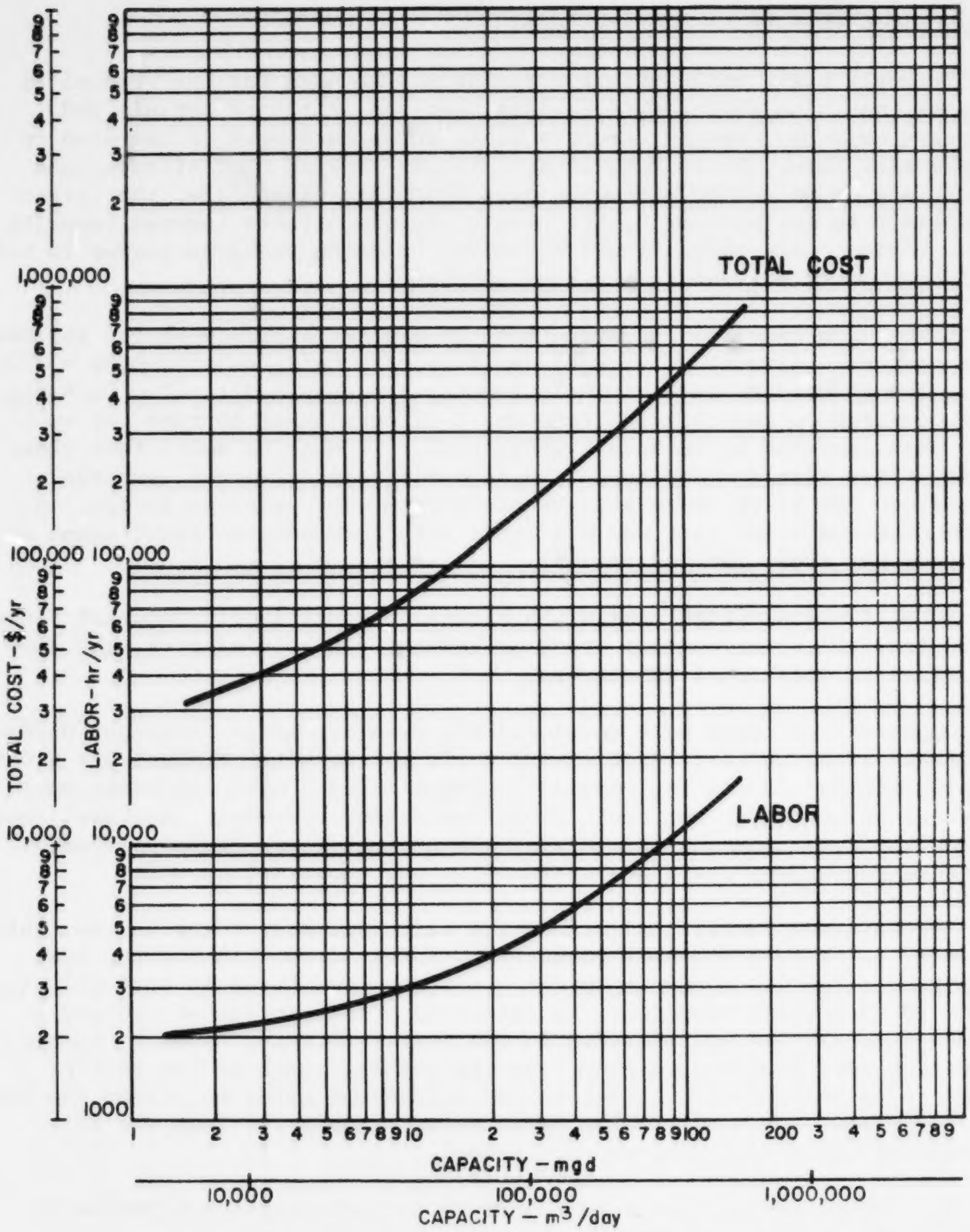
| Plant Flow Rate - mgd | Energy kw-hr/yr Building | Energy kw-hr/yr Process | Energy kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| 1.5 | 44,120 | 1,470 | 45,590 | 6,960 | 2,230 | 30,630 |
| 7.5 | 151,850 | 7,370 | 159,220 | 30,690 | 3,090 | 66,370 |
| 15 | 279,070 | 14,730 | 293,800 | 59,040 | 3,570 | 103,550 |
| 75 | 1,190,160 | 73,700 | 1,263,860 | 286,830 | 9,600 | 420,750 |
| 150 | 2,165,890 | 147,310 | 2,313,200 | 567,880 | 17,460 | 811,880 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
GRAVITY ION EXCHANGE SOFTENING

FIGURE 82



OPERATION AND MAINTENANCE
GRAVITY ION EXCHANGE SOFTENING

FIGURE 83

## CONSTRUCTION COST

### Pressure Ion Exchange - Nitrate Removal

Strongly basic anion exchange resins may be used for the removal of nitrates, and also sulfates, fluorides, and some forms or organic and inorganic mercury. When a strongly basic anion exchanger is operated on the chloride form, the sulfate is selectively removed over nitrate, and the nitrate is selectively removed over fluoride. Therefore, the larger the nitrate to sulfate ratio, the greater is the nitrate removal capacity of the resin. Generally, fluoride removal by anion exchange resins is not considered practical due to the low capacity.

Costs were developed for treatment of a water supply with the following anion content: nitrate = 100 mg/l; sulfate = 80 mg/l; other anions = 120 mg/l. The assumed nitrate capacity for the strongly basic anion exchange resin operated on the chloride form was 7 kilograins of nitrate per cubic foot, when operated to nitrate breakthrough. It must be noted that other quality water supplies may result in significantly different exchange capacities, and pilot scale studies are recommended prior to design. A sodium chloride regenerant was utilized, with a regenerant requirement of 15 pounds per cubic foot of resin.

A total regeneration time of 54 minutes was utilized. Backwash required 10 minutes, the brine contact and displacement rinse 24 minutes, and the fast rinse an additional 20 minutes.

Construction costs were developed for pressure anion exchange, using fabricated steel contact vessels with a 100 psi working pressure and a baked phenolic lining. A six foot bed depth was utilized, although tanks were sized for up to 80 percent resin expansion during backwash. A gravel layer between the resin and the underdrains was not utilized. Resin placement and backwash pumping costs are included in the construction cost.

Regeneration facilities include two salt storage/brining basins, which are open, reinforced concrete structures, constructed with the top foot above ground level. Saturated brine withdrawn from the salt storage/brining basins is 26 percent by weight. A saturated brine storage of two and a half days normal use was provided in the storage/brining basins. Pumping facilities were included to pump from the brining tanks to the contact vessels. An eductor is utilized to add sufficient water to dilute the brine to a 10 percent concentration as it is being transferred from the salt storage/brining tank to the contact vessel.

Conceptual designs which were used to estimate costs are presented in Table 79.

## TABLE 79

## CONCEPTUAL DESIGNS

## PRESSURE ION EXCHANGE - NITRATE REMOVAL

| Plant Capacity - mgd | Number of Contactors | Diameter of Contactors - ft | Housing - ft$^2$ |
|---|---|---|---|
| 1.2 | 2 | 8 | 930 |
| 3.9 | 3 | 12 | 2,375 |
| 6.5 | 5 | 12 | 3,910 |
| 13 | 10 | 12 | 6,920 |

No facilities are included in the construction cost for disposal of spent regenerant. Construction costs for pressure ion exchange softening are presented in Figure 84 and summarized in Table 80.

## OPERATION AND MAINTENANCE COST

### Ion Exchange - Nitrate Removal

Electrical energy costs are for backwash pumping, rinse pumping, regenerant pumping, and building heating, lighting, and ventilation. Backwash pumping was based upon a ten minute wash at 3 gpm/ft$^2$. Regenerant pumping was based upon a rate of 1 gallon per minute per cubic foot of resin for 24 minutes, and fast rinse pumping was based upon a rate of 8 gallons per minute/square foot for twenty minutes. All pumping was assumed to be against a 25 foot TDH.

Maintenance material costs for periodic repair and replacement of components were estimated based on one percent of the construction cost. Resin replacement costs are for resin lost annually by physical attrition as well as loss of capacity due to chemical fouling. As anion resin is typically replaced every 3 to 5 years, a 25 percent annual resin replacement was included to account for resin fouling and resin loss. Regenerant costs are not included in the maintenance material cost.

Labor requirements are for operation and maintenance of ion exchange vessels and the pumping facilities. Hours were estimated based upon comparable size filtration plants and filter pumping facilities. Labor requirements are also included for periodic media addition and replacement of the media every 4 years.

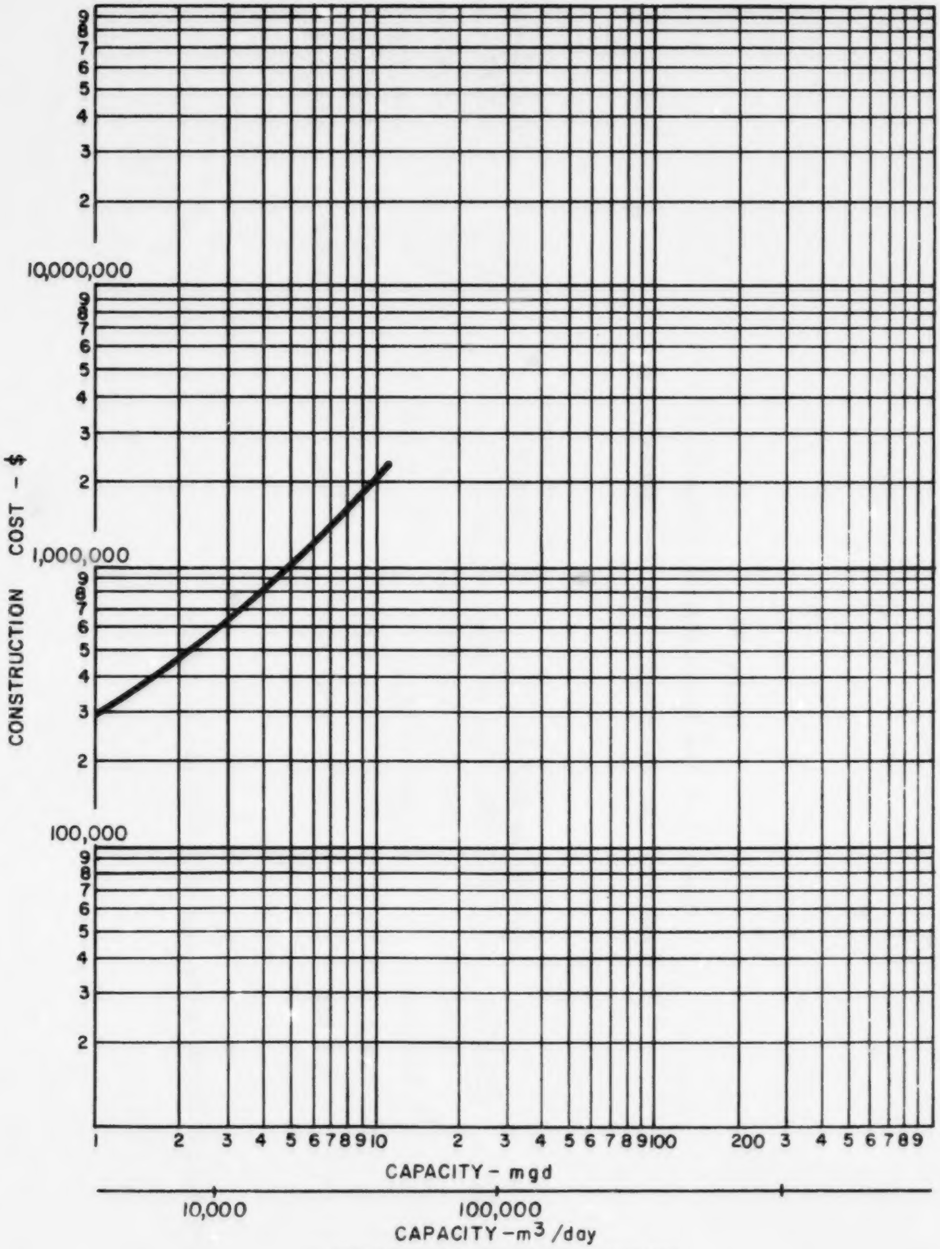
No costs are included for spent brine disposal. Operation and maintenance curves are presented in Figures 85 and 86 and are summarized in Table 81.

## Table 80

## Construction Cost

## Pressure Ion Exchange - Nitrate Removal

| | Plant Capacity - mgd | | | |
|---|---|---|---|---|
| | 1.1 | 3.7 | 6.1 | 12.3 |
| Excavation and Sitework | $ 700 | 1,080 | 1,400 | 1,870 |
| Manufactured Equipment | | | | |
| Equipment | 37,670 | 84,440 | 129,860 | 243,410 |
| Media | 87,460 | 295,190 | 491,990 | 983,970 |
| Concrete | 2,270 | 3,380 | 4,480 | 5,960 |
| Steel | 3,470 | 5,150 | 6,820 | 9,020 |
| Labor | 26,160 | 63,030 | 110,660 | 223,480 |
| Pipe and Valves | 13,210 | 36,480 | 65,610 | 131,220 |
| Electrical and Instrumentation | 26,460 | 36,790 | 58,100 | 114,830 |
| Housing | 20,470 | 33,300 | 53,630 | 180,500 |
| SUBTOTAL | 217,170 | 558,840 | 922,550 | 1,793,580 |
| Miscellaneous and Contingency | 32,580 | 83,830 | 138,380 | 269,040 |
| TOTAL | $ 249,750 | 642,670 | 1,060,930 | 2,062,620 |



CONSTRUCTION COST
PRESSURE ION EXCHANGE-NITRATE REMOVAL

FIGURE 84

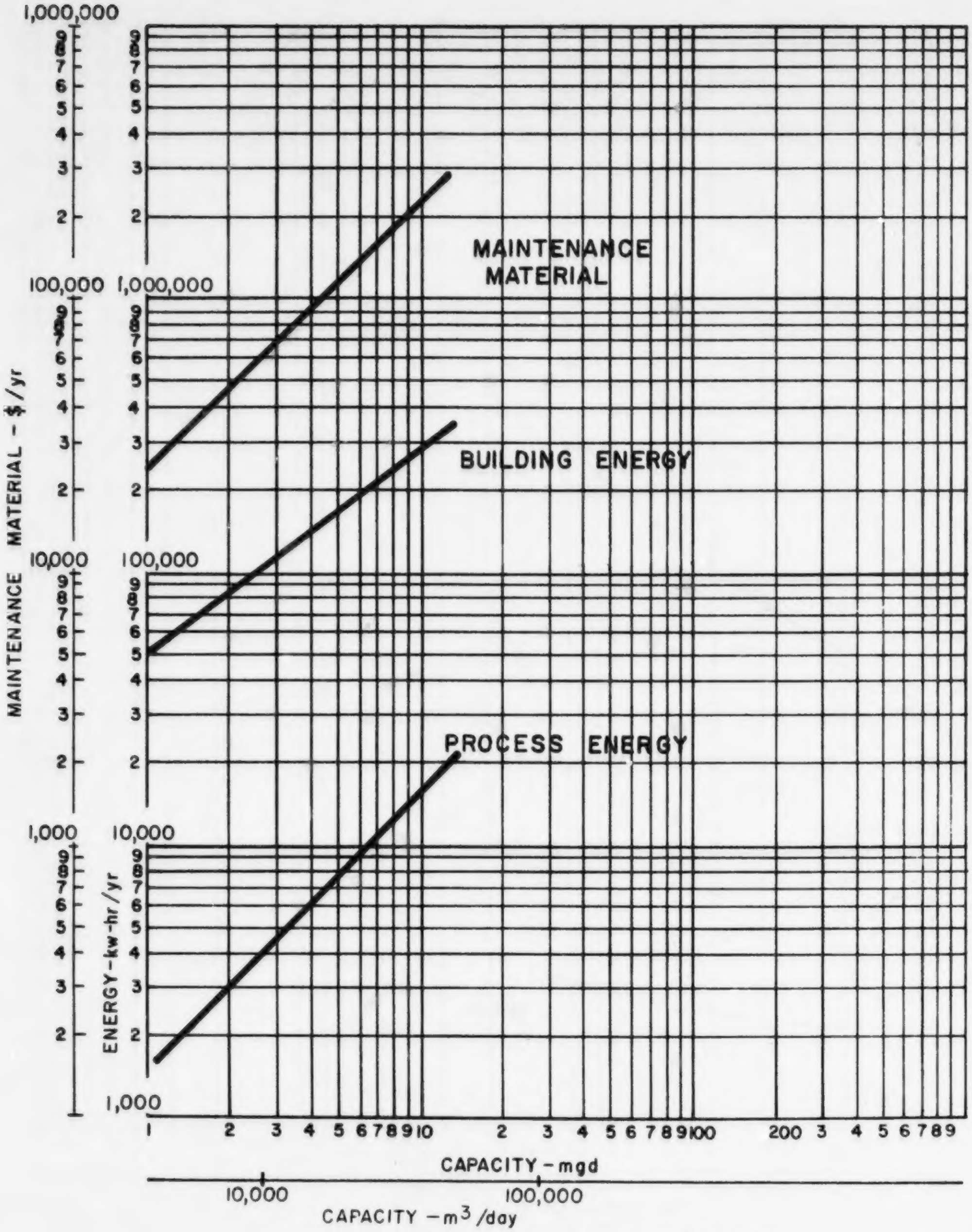
## Table 81

## Operation and Maintenance Summary

## Pressure Ion Exchange - Nitrate Removal

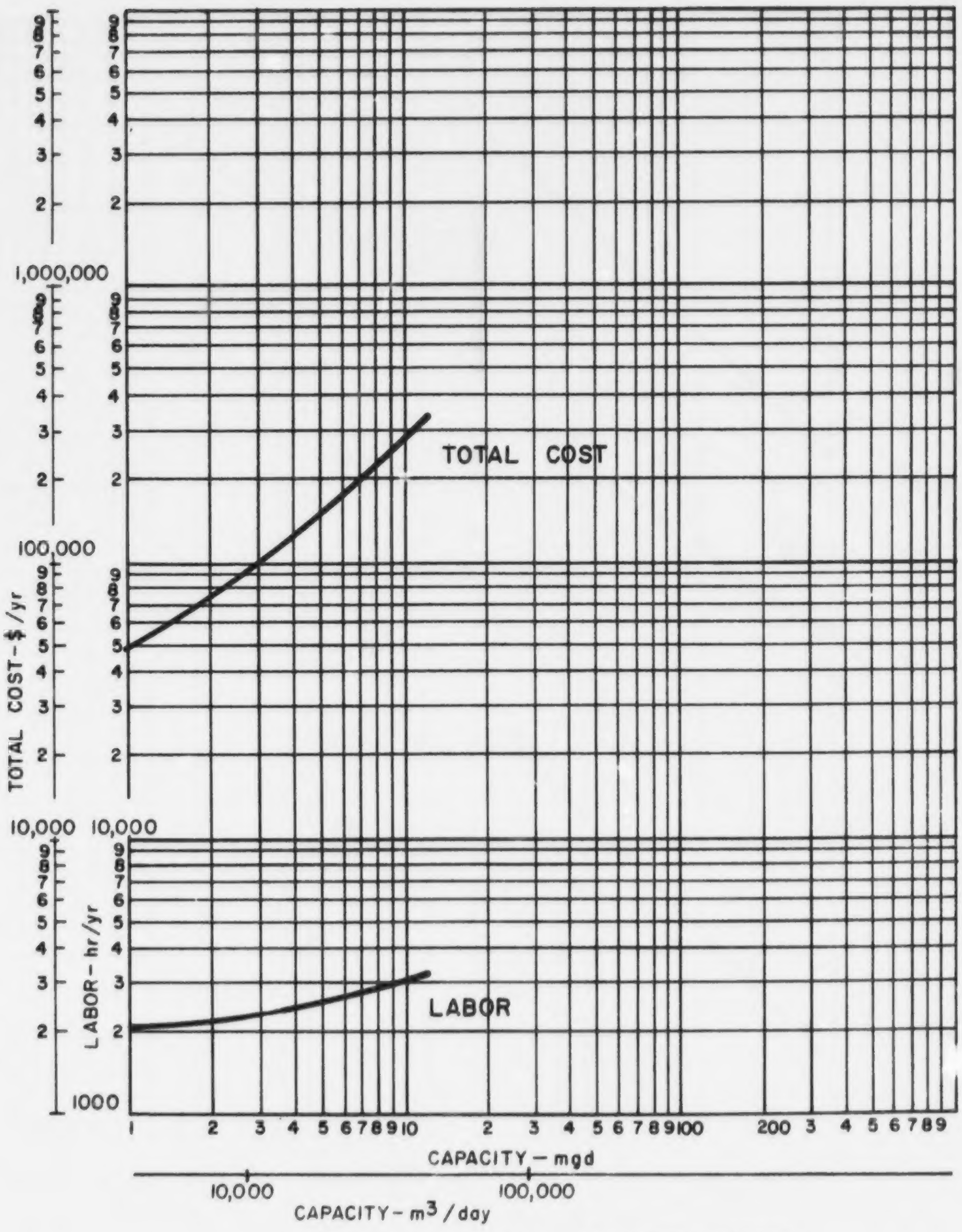
| Plant Capacity - mgd | Energy kw-hr/yr | | | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
| | Building | Process | Total | | | |
| 1.1 | 56,090 | 1,900 | 57,990 | 24,110 | 2,200 | 47,850 |
| 3.7 | 126,400 | 6,380 | 132,780 | 79,730 | 2,500 | 108,710 |
| 6.1 | 203,150 | 10,510 | 213,660 | 132,670 | 3,000 | 169,080 |
| 12.3 | 313,960 | 21,200 | 335,160 | 264,720 | 3,300 | 307,770 |

*Calculated using $0.03/kw-hr and $10.00/hour of labor



OPERATION AND MAINTENANCE
PRESSURE ION EXCHANGE—NITRATE REMOVAL

FIGURE 85



OPERATION AND MAINTENANCE
PRESSURE ION EXCHANGE — NITRATE REMOVAL

FIGURE 86

## CONSTRUCTION COST

### Activated Alumina for Fluoride Removal

Water supplies with fluoride concentrations up to 10 mg/l and higher can be effectively treated by contact with activated alumina. Fluoride reductions to less than 0.5 mg/l are generally achieved by activated alumina contact, with blending being utilized to meet desired fluoride concentrations. Treatment is generally selective for fluoride and arsenic, although small amounts of other anions often are removed. Regeneration of the activated alumina with caustic removes both exchanged fluoride and arsenic.

Facilities were sized based upon a fluoride exchange capacity of 0.6 percent by weight, or 0.25 pounds of fluoride per cubic foot of activated alumina, and a fluoride reduction from 3 mg/l to 0.5 mg/l. Operation was assumed to be at pH 5.5, although higher pH values may be used with a resultant lower exchange capacity. Regeneration facilities were sized on the basis of batch rather than continuous regeneration, due to the significant savings in regeneration chemical cost when batch regeneration is utilized. However, a reduced capacity of the facilities results from the increased regeneration time. Two one hour contacts with 0.1 N sodium hydroxide were included for fluoride removal from the alumina, followed by a one-half hour contact with 0.05 N sulfuric acid for neutralization of remaining caustic. An activated alumina void volume of 2.28 gallons per cubic foot and in place resin costs of $13.86 per cubic foot were utilized. Feed water was assumed to be sufficiently low in suspended solids so that backwashing was only occasionally necessary, although backwashing facilities are included in the construction cost.

Construction costs were developed for pressure ion exchange using the conceptual information presented in Table 82. The contact vessels are fabricated steel with a baked phenolic lining, and constructed for 100 psi working pressure. The depth of resin was 8 feet, and the contact vessel was designed for 80 percent media expansion during backwash. A gravel layer between underdrains and media was not included.

Regeneration storage facilities were sized for 30 days requirement. Sodium hydroxide required for regeneration was assumed to be purchased in a solid form for capacities less than 10 mgd, and as a 50 percent solution for larger plants. A caustic dilution tank was included when the 50 percent solution was used. Due to the small requirement for sulfuric acid, a concentrated sulfuric acid storage tank was only included for 70 mgd and larger plants, although a sulfuric acid dilution tank was included in each case. Metering pumps were included for transfer of concentrated caustic and sulfuric acid to the dilution tanks, and pumping facilities were included to pump from the dilution tanks to the exhausted contactor.

## TABLE 82

## CONCEPTUAL DESIGNS

## ACTIVATED ALUMINA FOR FLUORIDE REMOVAL

| Plant Capacity - mgd | Number of Contactors | Diameter of Contactors - ft | Housing - $ft^2$ |
|---|---|---|---|
| 0.7 | 2 | 6 | 252 |
| 2.0 | 2 | 10 | 700 |
| 6.8 | 5 | 12 | 1,980 |
| 27 | 20 | 12 | 7,920 |
| 54 | 40 | 12 | 15,840 |
| 135 | 100 | 12 | 31,680 |

All facilities were assumed to be located indoors. Construction costs are presented in detail in Table 83 and are also shown in Figure 87.

## OPERATION AND MAINTENANCE COST

### Activated Alumina for Fluoride Removal

Electrical energy costs are for regenerant pumping, occasional backwash pumping, and building heating, ventilation and lighting. The latter requirements constitute the majority of the energy requirements, and use of an outdoor installation would have a very significant impact on energy requirements. Process energy is extremely small, and is only for regenerant pumping. If backwash is required, process energy requirements would increase significantly.

Maintenance material costs are for periodic repair and replacement of components, and were estimated on the basis of one percent of the construction cost. An activated alumina replacement cost was also included in maintenance material, at an annual rate of 10 percent. Regenerant costs are not included in the maintenance material costs.

Labor requirements are principally for regenerant preparation and regeneration of the activated alumina. Labor requirements also include periodic media addition to make up losses and occasional replacement.

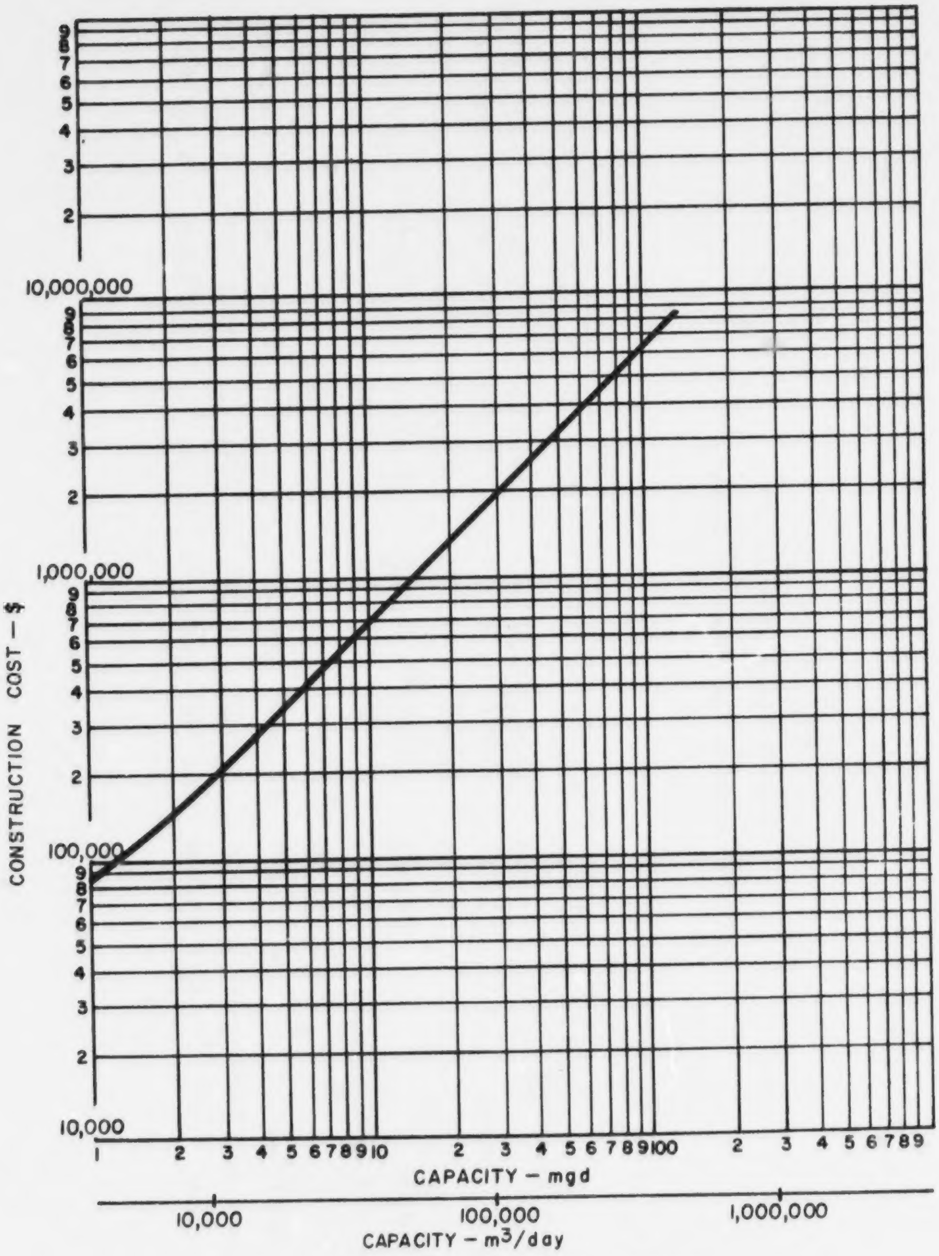
Operation and maintenance curves are presented in Figures 88 and 89 and are summarized in Table 84.

## Table 83

## Construction Cost

## Activated Alumina for Fluoride Removal

| | Plant Capacity - | | | | | |
|---|---|---|---|---|---|---|
| | 0.7 | 2.0 | 6.8 | 27 | 54 | 135 |
| Manufactured Equipment | | | | | | |
| Equipment | $ 25,230 | 42,020 | 130,390 | 492,240 | 972,090 | 2,417,380 |
| Activated Alumina | 7,820 | 13,920 | 78,310 | 313,240 | 626,470 | 1,566,180 |
| Labor | 9,780 | 12,830 | 45,680 | 182,690 | 365,400 | 1,220,070 |
| Pipe and Valves | 15,300 | 18,180 | 64,940 | 257,030 | 510,510 | 1,287,040 |
| Electrical and Instrumentation | 9,600 | 10,850 | 21,300 | 57,600 | 113,700 | 272,000 |
| Housing | 6,500 | 25,800 | 58,000 | 197,000 | 350,000 | 695,000 |
| SUBTOTAL | 74,230 | 123,600 | 398,620 | 1,499,800 | 2,938,170 | 7,448,670 |
| Miscellaneous and Contingency | 11,130 | 18,540 | 59,780 | 224,970 | 440,730 | 1,117,300 |
| TOTAL | $ 85,360 | 142,140 | 458,410 | 1,724,770 | 3,378,900 | 8,565,970 |



CONSTRUCTION COST
ACTIVATED ALUMINA-FLUORIDE REMOVAL

FIGURE 87

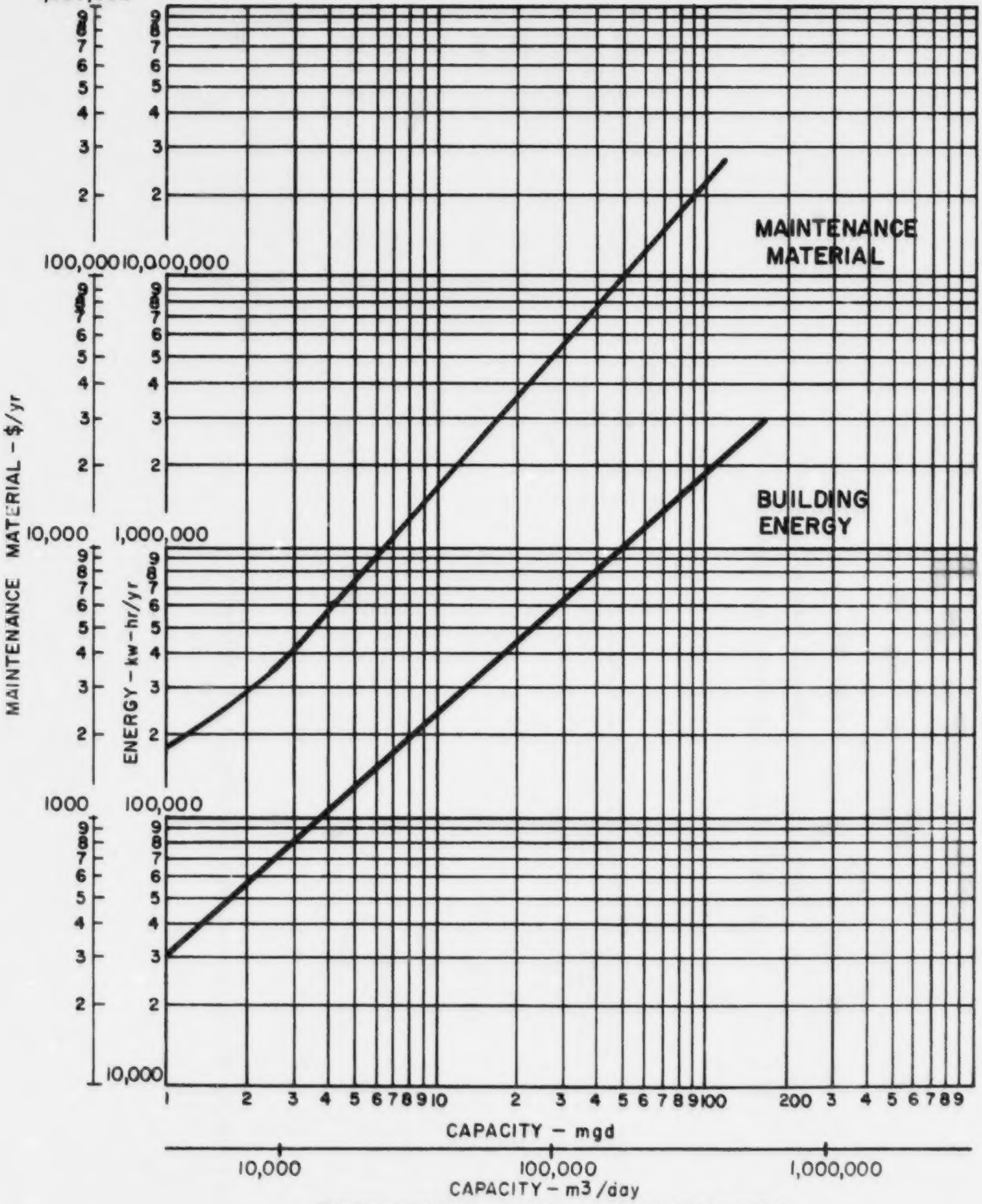
### Table 84

### Operation and Maintenance Summary

### Activated Alumina for Fluoride Removal

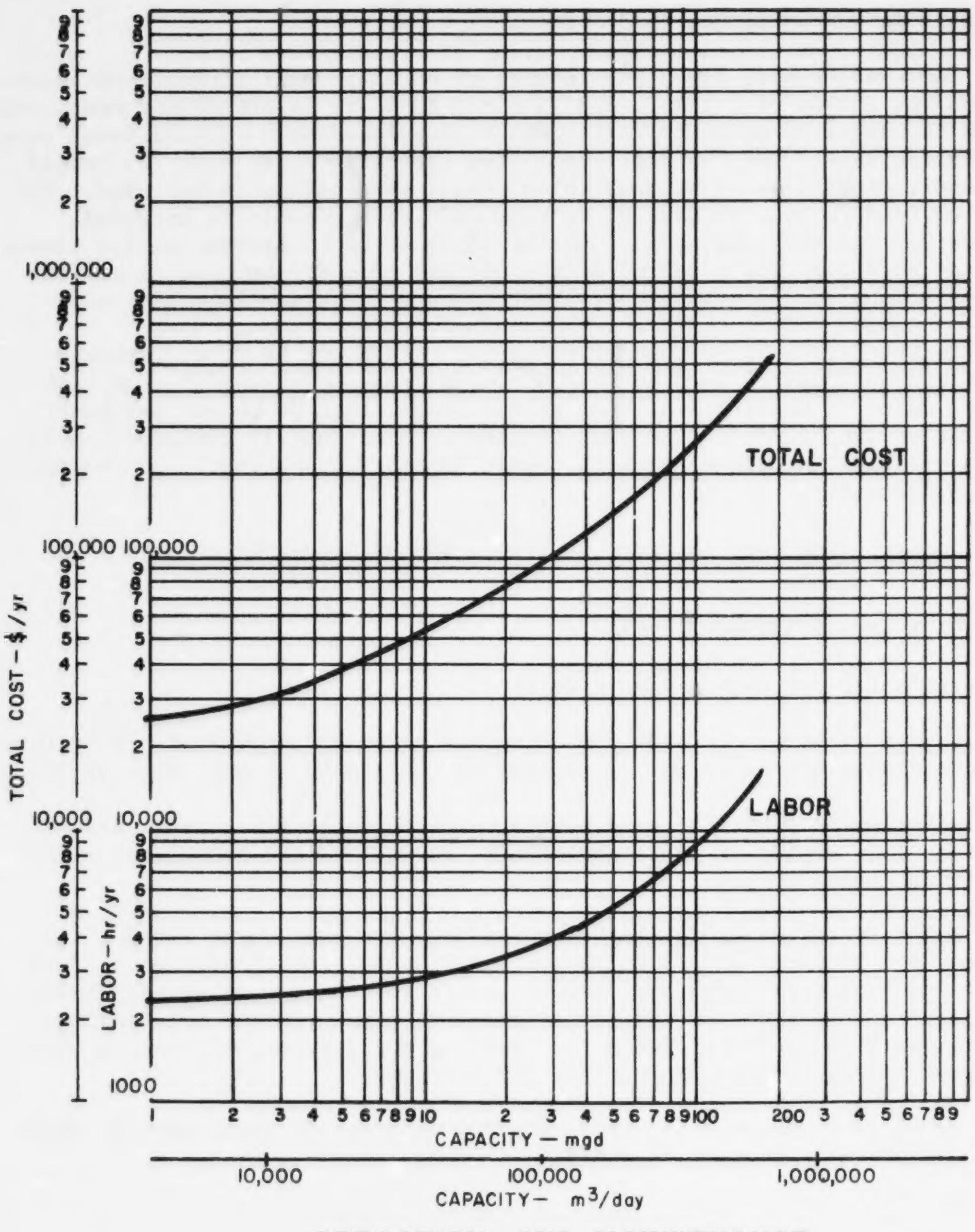
| Plant Capacity mgd | Energy kw-hr/yr |  |  | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
|  | Building | Process | Total |  |  |  |
| 0.7 | 17,640 | 10 | 17,650 | 1,780 | 2,400 | 26,310 |
| 2.0 | 49,000 | 10 | 49,100 | 3,040 | 2,580 | 30,190 |
| 6.8 | 138,600 | 10 | 138,600 | 14,030 | 2,940 | 47,590 |
| 27 | 554,400 | 10 | 554,410 | 55,660 | 4,490 | 117,190 |
| 54 | 1,108,800 | 30 | 1,108,830 | 111,130 | 7,560 | 219,990 |
| 135 | 2,217,600 | 70 | 2,217,670 | 278,680 | 17,580 | 521,010 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
ACTIVATED ALUMINA—FLUORIDE REMOVAL

FIGURE 88



OPERATION AND MAINTENANCE
ACTIVATED ALUMINA – FLUORIDE REMOVAL

FIGURE 89

## CONSTRUCTION COST

### Powdered Activated Carbon Feed Systems

The systems were sized for feeding of an 11 percent slurry (one percent carbon per gallon of water). The 11 percent slurry is stored and continuously mixed in uncovered concrete tanks, which are placed below ground level except for approximately the top foot. For feed capacities less than 700 pounds per hour, eight days of storage in two equal size basins is included. For greater feed rates, two days of storage in a single basin is included. Mixers were sized based upon a G value equal to 600. Storage/mixing basins include equipment for powdered activated carbon feed from bags in smaller installations and from trucks or railroad cars in larger installations.

For feed rates less than 20 pounds of carbon per hour, a diaphragm type metering pump is used to feed directly from the mixing/storage tank to the point of application. For rates greater than 20 pounds per hour, a positive displacement type pump is used to continuously transfer slurry to an overhead rotodip volumetric feeder, which feeds directly to the point of application.

Construction cost is shown in Figure 90 and presented in detail in Table 85.

## OPERATION AND MAINTENANCE COST

### Powdered Activated Carbon Feed Systems

Energy requirements are based upon the rated horsepower of pump motors and continuous mixing of the 11 percent carbon slurry at a G value of 600.

Maintenance material requirements consist of oil for gearbox drives and for minor repair of pumps and motors, as well as the associated electrical switching gear.

Labor requirements for carbon unloading were based upon rates of 10 minutes per 50 pound bag, 2 hours per 9,000 pound truck load, and 4 hours per 27,000 pound railroad car. Requirements for the mixing storage basin are 30 minutes per day per basin for inspection and routine maintenance, and 16 hours per year per basin for cleaning and gearbox oil change. Slurry pumps would require one manhour per day per pump.

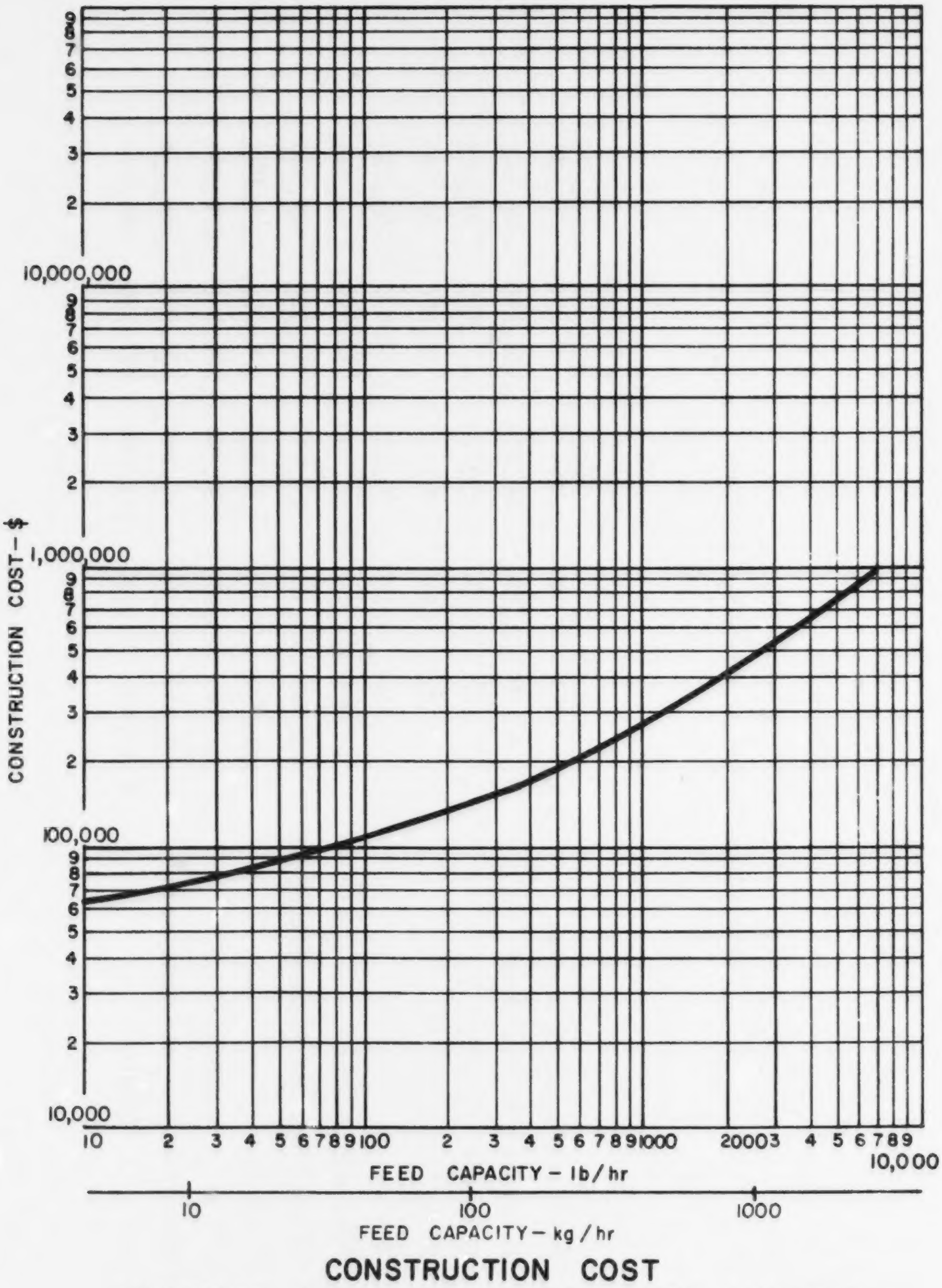
Table 86 summarizes the operation and maintenance requirements, which are also shown in Figures 91 and 92.

## Table 85

## Construction Cost

## Powdered Activated Carbon Feed Systems

| | Feed Capacity - Pound/Hour | | | | |
|---|---|---|---|---|---|
| | 3.5 | 35 | 350 | 700 | 7,000 |
| Excavation and Sitework | $ 90 | 340 | 1,410 | 2,120 | 10,600 |
| Manufactured Equipment | 8,180 | 21,200 | 66,410 | 118,810 | 506,640 |
| Concrete | 270 | 1,000 | 3,910 | 5,580 | 27,890 |
| Steel | 230 | 1,640 | 6,730 | 9,800 | 48,990 |
| Labor | 560 | 2,120 | 8,520 | 12,510 | 62,550 |
| Pipe and Valves | 17,160 | 17,450 | 17,790 | 18,580 | 84,350 |
| Electrical and Instrumentation | 22,490 | 23,320 | 24,930 | 50,580 | 109,780 |
| Housing | 6,000 | 6,000 | 6,000 | 6,000 | 6,000 |
| SUBTOTAL | 54,980 | 73,070 | 135,700 | 223,980 | 856,800 |
| Miscellaneous and Contingency | 8,250 | 10,960 | 20,360 | 33,600 | 128,520 |
| TOTAL | $ 63,230 | 84,030 | 156,060 | 257,580 | 985,320 |



CONSTRUCTION COST
POWDERED ACTIVATED CARBON FEED SYSTEMS

FIGURE 90

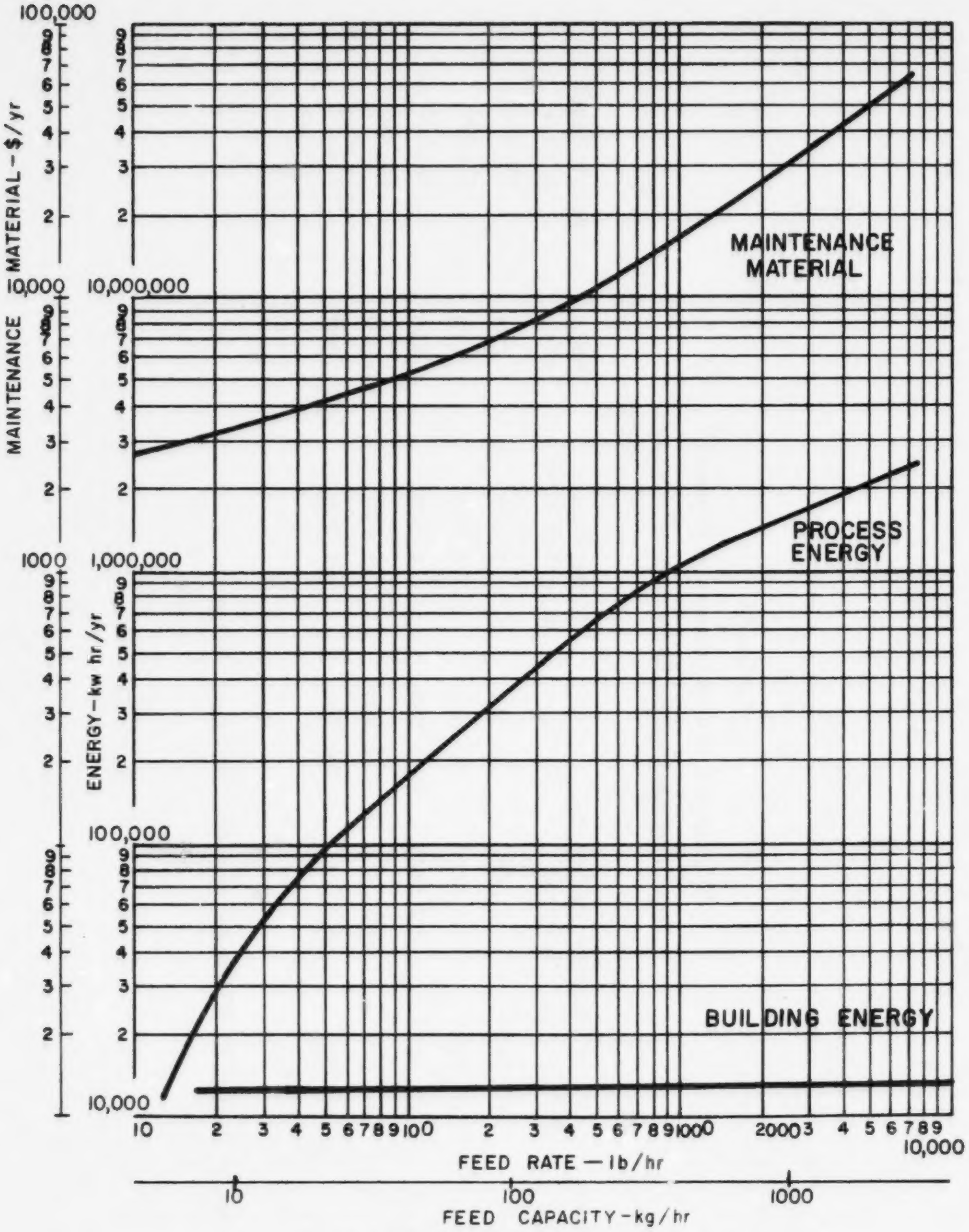
## Table 86

### Operation and Maintenance Summary

### Powdered Activated Carbon Feed Systems

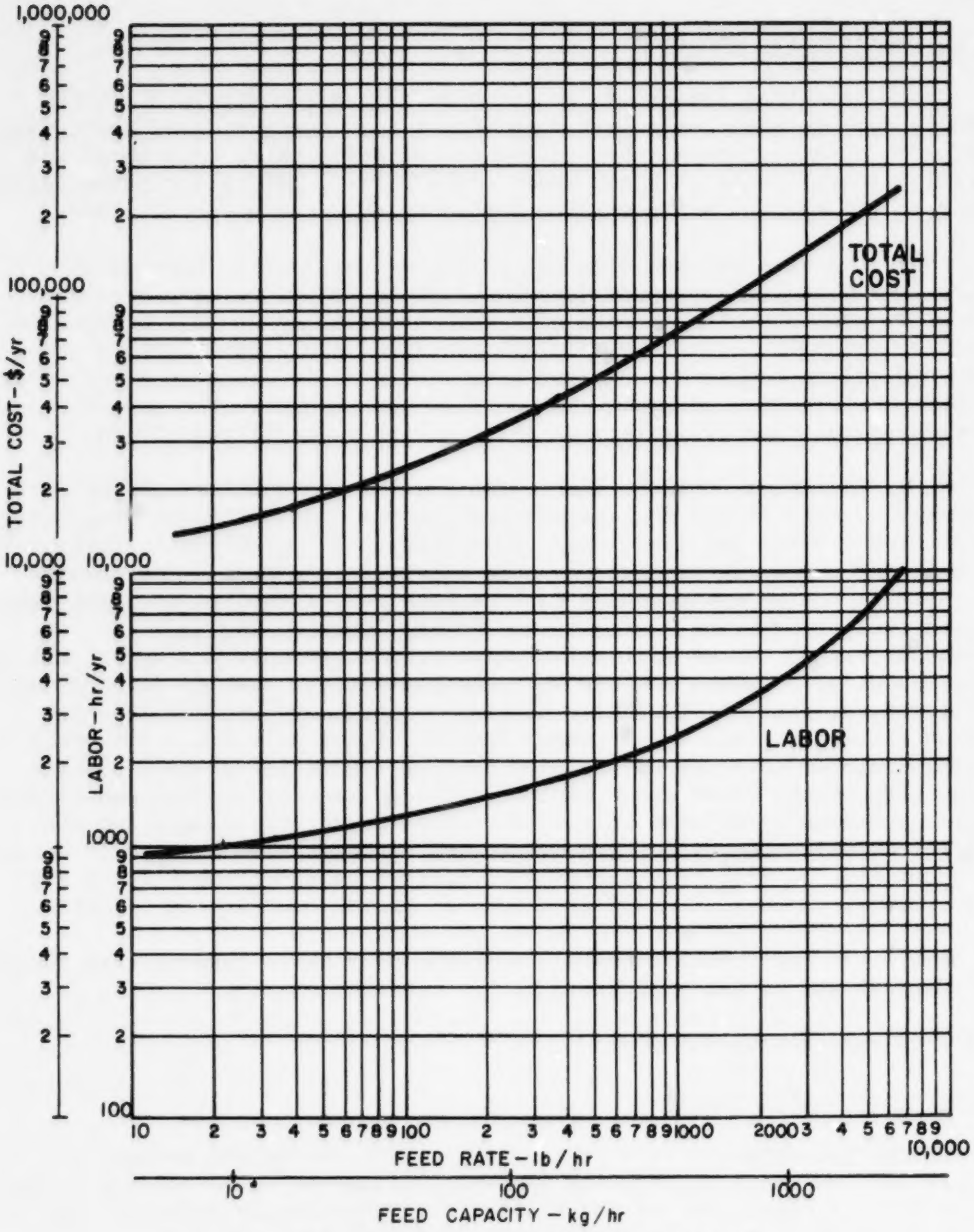
| Feed Rate lb/hr | Energy kw-hr/yr |  |  | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|
|  | Building | Process | Total |  |  |  |
| 3.5 | 10,260 | 7,000 | 17,260 | 2,000 | 850 | 11,020 |
| 35 | 10,260 | 59,000 | 69,260 | 4,000 | 1,110 | 17,200 |
| 350 | 10,260 | 482,000 | 492,260 | 8,000 | 1,840 | 41,170 |
| 700 | 10,260 | 946,000 | 956,260 | 14,000 | 2,010 | 44,700 |
| 7,000 | 10,260 | 2,294,000 | 2,304,260 | 62,000 | 11,000 | 241,130 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
POWDERED ACTIVATED CARBON FEED SYSTEMS

FIGURE 91



OPERATION AND MAINTENANCE
POWDERED ACTIVATED CARBON FEED SYSTEMS

FIGURE 92

## CONSTRUCTION COST

### Pressure Filtration Plants

Costs have been developed for pressure filtration plants which are suitable for use with 24-36 inch deep filter beds consisting of rapid sand, dual media or mixed media. Regardless of the media used, structural and hydraulic requirements of these media are similar. Filtration rates ranging from 2 to 7-8 gpm/ft$^2$ are possible, depending upon the media utilized.

Cost estimates are based on use of either vertical or horizontal cylindrical ASME code pressure vessels of 50 to 75 psi working pressure. Each plant consists of a minimum of 4 vessels, with conceptual designs as shown in Table 87. Filter vessels are provided with a pipe lateral underdrain and filter media is supported by graded gravel. This type underdrain is suitable for water backwash with surface wash assist. For air-water backwashing the pipe laterals are replaced with a nozzel underdrain.

Costs include a complete filtration plant with vessels, cylinder operated butterfly valves, filter face piping and headers within the filter gallery, filter flow control and measurement instrumentation, headloss instrumentation and a master filter control panel. The filters are designed to backwash automatically on an input signal such as headloss, turbidity breakthrough, elapsed time or by manual activation. Not included in the cost estimate are supply piping to the filtration units from other unit processes, filter supply pumping, backwash storage and pumping, surface wash or airwash supply facilities, or filtration media. Housing requirements are based on the minimum rectangular space into which the facilities will fit. The basic housing includes covering of the pipe gallery (including a small portion of the ends of the tanks and a minimal service area for control panel) and other appurtenances related to the filtration structure, except for the 1 mgd plant which because of its design and configuration is totally housed. The total housing requirement is for complete housing of the filters and pipe gallery, which would only be necessary in the most severe climates.

Estimated construction costs, including only basic housing, are shown in Figure 93 and in Table 88.

## OPERATION AND MAINTENANCE COST

### Pressure Filtration Plants

Energy requirements were developed from the conceptual designs for process and for heating, lighting and ventilating the basic housing requirement. Process energy is for the filtration system supply pumps and backwash pumps. Continuous 24 hour per day, 365 days per year operation with one backwash per day of 10 minutes duration was assumed. It was further assumed that the surface wash supply would be obtained from the pressurized distribution system with suitable means for backflow prevention.

## Table 87

## Conceptual Designs

## Pressure Filtration Plants

| Plant Flow mgd | Total Filter Area, ft² (2) | Filter Vessels | | | Plant Area Requirements, ft² (3) | Housing, ft² | |
|---|---|---|---|---|---|---|---|
| | | Number | Diameter and Lengths, ft | Area Each, ft² | | Basic | Total(4) |
| 1 | 140 | 4 | 7 vertical (1) | 35 | 2,100 | 2,100 | 2,100 |
| 10 | 1,400 | 4 | 10 x 35 | 350 | 5,000 | 2,000 | 5,000 |
| 50 | 7,000 | 18 | 10 x 40 | 400 | 13,750 | 8,200 | 13,750 |
| 100 | 14,000 | 35 | 10 x 40 | 400 | 26,050 | 14,950 | 26,050 |
| 200 | 28,000 | 70 | 10 x 40 | 400 | 64,200 | 28,500 | 64,200 |

(1) Vertical pressure filters approximately 10' tall

(2) Filter rate approximately 5 $gpm/ft^2$

(3) Rectangular space covering entire plant area

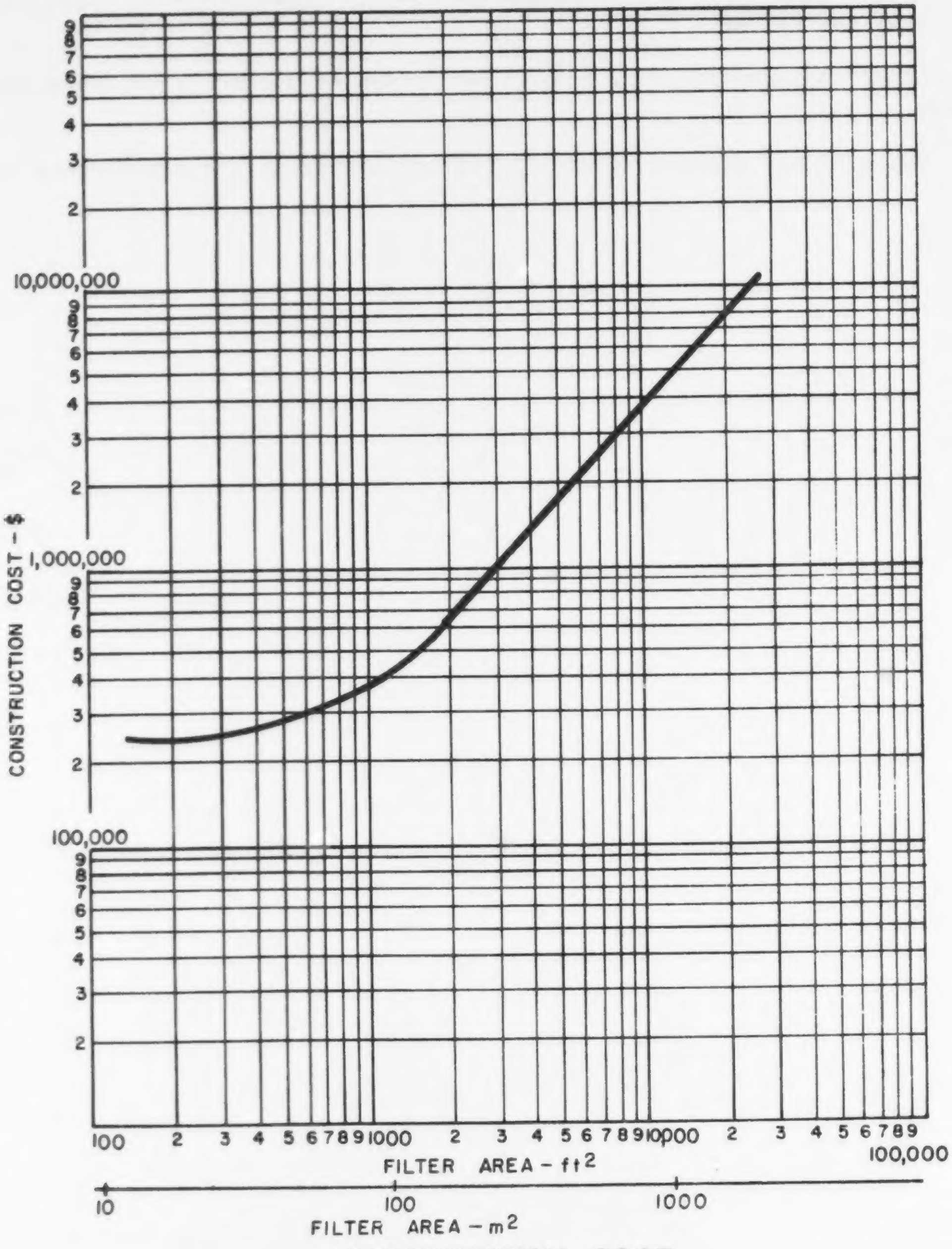
(4) Entire plant enclosed

## Table 88

## Construction Cost

## Pressure Filtration Plants

| | Plant Capacity, mgd | | | | |
|---|---|---|---|---|---|
| | 1 | 10 | 50 | 100 | 200 |
| Filter Area - ft$^2$ | 140 | 1,400 | 7,000 | 14,000 | 28,000 |
| Excavation and Sitework | $ 930 | 1,650 | 3,850 | 7,600 | 13,800 |
| Manufactured Equipment | 94,890 | 236,250 | 1,114,000 | 2,343,000 | 4,435,000 |
| Concrete | 650 | 890 | 4,440 | 8,880 | 16,650 |
| Steel | 260 | 450 | 2,270 | 4,540 | 9,080 |
| Labor | 9,150 | 23,320 | 176,000 | 352,000 | 704,000 |
| Piping and Valves | 22,230 | 66,700 | 598,000 | 1,196,000 | 2,392,000 |
| Electrical and Instrumentation | 19,180 | 49,400 | 284,780 | 586,800 | 1,135,580 |
| Housing | 61,600 | 58,700 | 197,600 | 343,800 | 641,300 |
| SUBTOTAL | 208,890 | 378,660 | 2,380,940 | 4,892,620 | 9,347,410 |
| Miscellaneous and Contingency | 31,330 | 56,800 | 357,140 | 726,390 | 1,402,110 |
| TOTAL | $ 240,220 | 435,460 | 2,738,080 | 5,569,010 | 10,749,520 |



CONSTRUCTION COST
PRESSURE FILTRATION PLANTS

FIGURE 93

Maintenance material costs are for additional filter media, charts and ink for recorders, and miscellaneous repair items for electrical control equipment and valves.

Labor requirements were based upon review of records from operating plants.

Table 89 and Figures 94 and 95 present operation and maintenance costs.

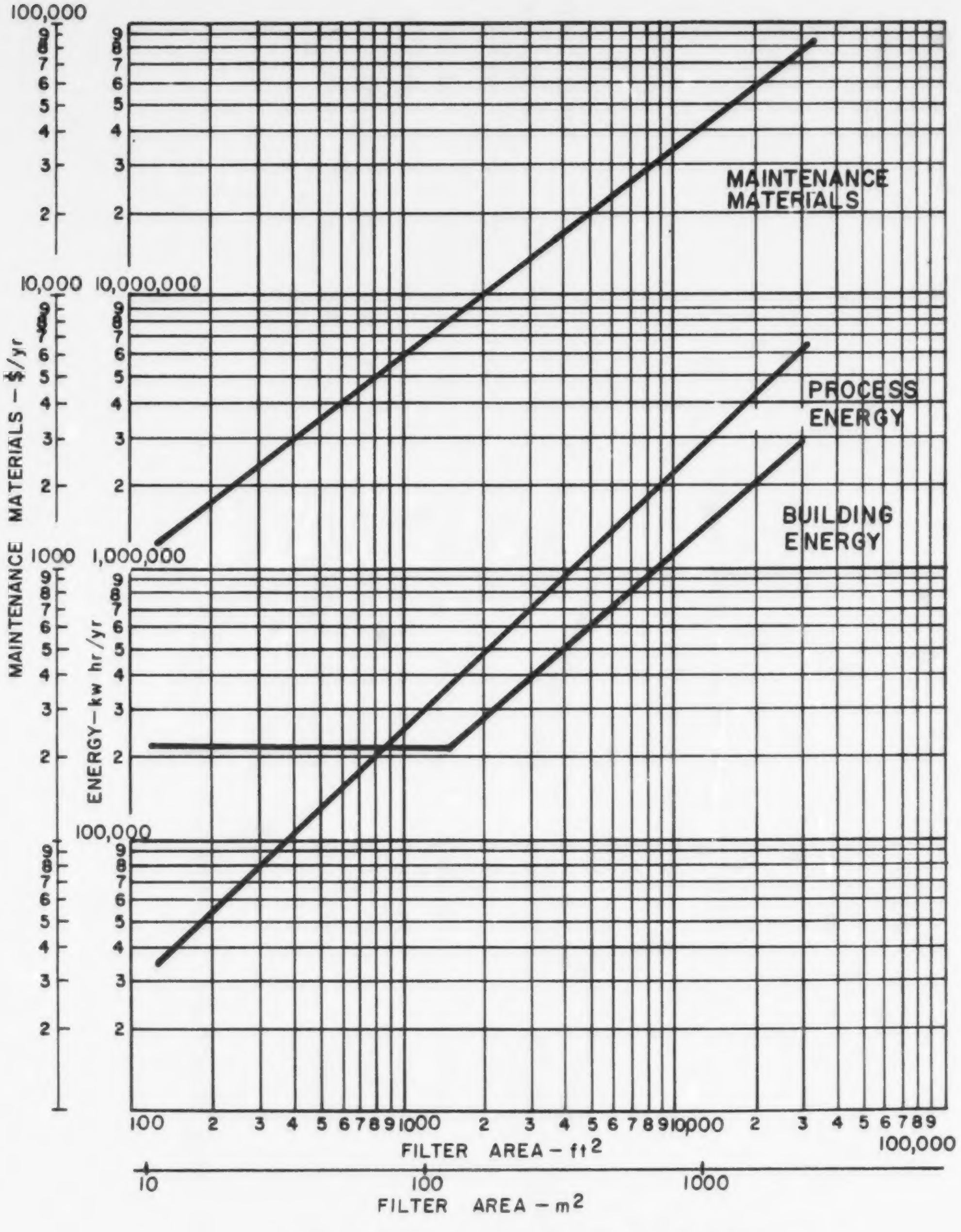
## Table 89

## Operation and Maintenance Summary

## Pressure Filtration Plants

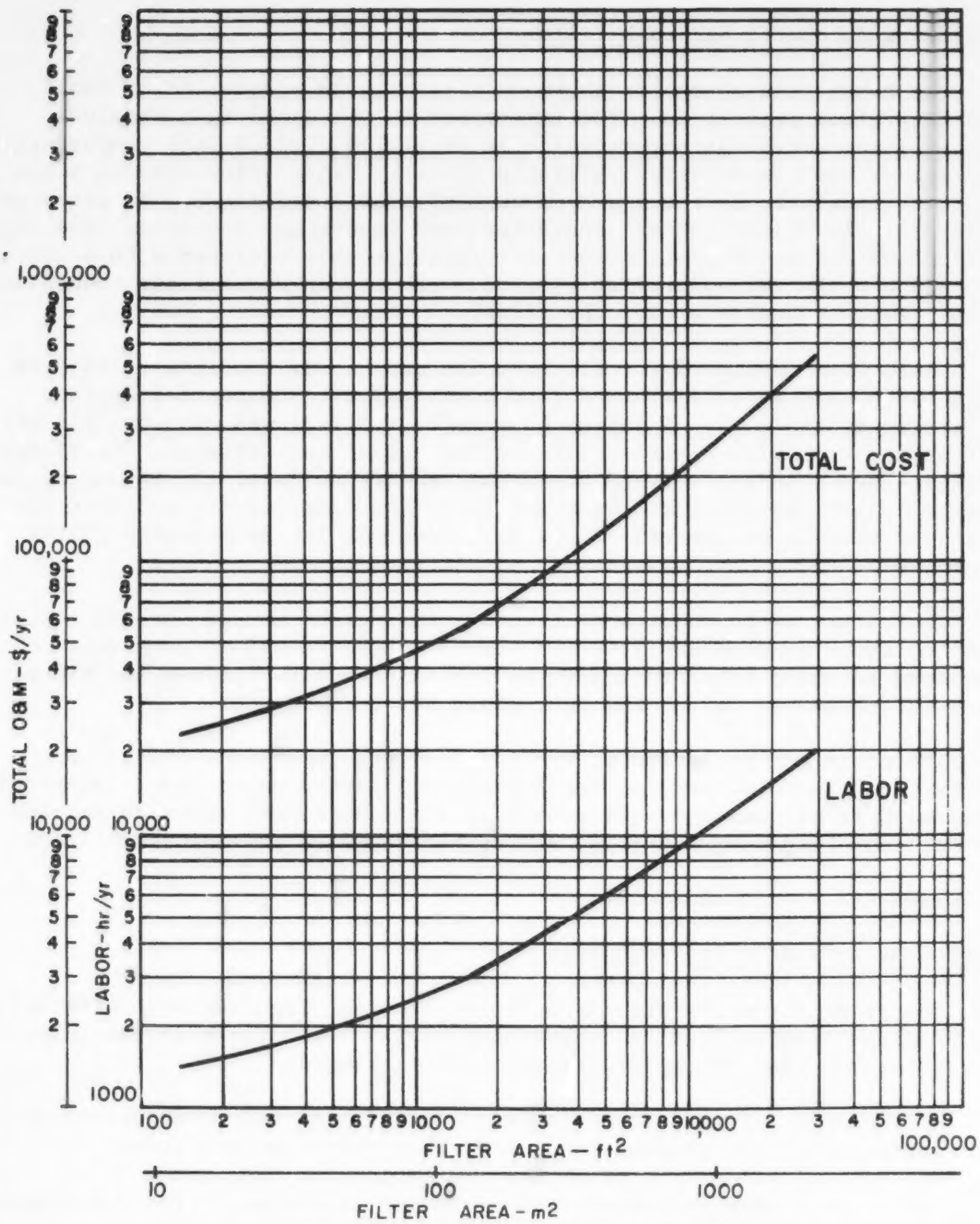
| Capacity, mgd | Filter Area, $ft^2$ | Energy kw-hr/yr Building | Energy kw-hr/yr Process | Energy kw-hr/yr Total | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|---|
| 1 | 140 | 215,460 | 35,597 | 251,007 | 1,200 | 1,460 | 23,330 |
| 10 | 1,400 | 205,200 | 330,316 | 535,516 | 7,300 | 2,920 | 52,565 |
| 50 | 7,000 | 841,320 | 1,652,776 | 2,494,096 | 26,000 | 8,760 | 188,420 |
| 100 | 14,000 | 1,533,870 | 3,303,155 | 4,837,025 | 45,000 | 11,680 | 306,910 |
| 200 | 28,000 | 2,924,100 | 6,606,310 | 9,530,410 | 80,000 | 20,440 | 570,310 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
PRESSURE FILTRATION PLANTS

FIGURE 94



OPERATION AND MAINTENANCE
PRESSURE FILTRATION PLANTS

FIGURE 95

## CONSTRUCTION COST

### Continuous Automatic Backwash Filter

The continuous automatic backwash filter is an adaptation of rapid sand filtration principles. The filter bed is contained in a shallow rectangular concrete structure which is laterally divided into compartments. Each compartment is in effect a single filter. Filter flow rate is based upon declining rate as there are no rate of flow controllers. An attractive feature of the filter is that operating head losses are generally less than one foot of water. A motor driven carriage assembly equipped with a backwash pump and a washwater collection pump backwashes each compartment sequentially as it traverses the length of the filter.

Costs were developed for filter units capable of handling flows from 1 mgd to 200 mgd at a filtration rate of 2 gpm/ft$^2$. Conceptual designs are listed in Table 90. A filter box depth of 5 feet was used for all size filters and each size plant utilizes a minimum of two filters. The filter units are essentially self-contained and require no inter-connecting piping. Filtered water, influent and backwash water are conducted to and from the filter by troughs or channels integrally cast within the concrete filter structure.

The nature of the equipment requires that it be housed for protection from inclement weather and freezing temperatures. Housing costs were developed assuming total enclosure of the filters with minimum additional space for access on two of the four sides for maintenance.

The costs are presented in Table 91 and Figure 96 and include the filtration structure, internal mechanical equipment, partitions, underdrains, rapid sand filter media (depth generally 11 inches) wash water collection trough, over-head pump carriage, electrical controls and instrumentation.

## OPERATION AND MAINTENANCE COST

### Continuous Automatic Backwash Filter

Energy requirements are for building heating, lighting and ventilation and pumping costs related to backwashing of the automatic backwash filter. It was assumed that the entire filter unit is housed.

Maintenance material costs include general supplies, pump maintenance and repair parts, replacement sand, and other miscellaneous items.

Labor costs were estimated from projected maintenance time requirements and are related to general supervision and maintenance.

Table 92 summarizes the operation and maintenance requirements which are illustrated graphically in Figures 97 and 98.

## Table 90

## Conceptual Design

## Continuous Automatic Backwash Filter

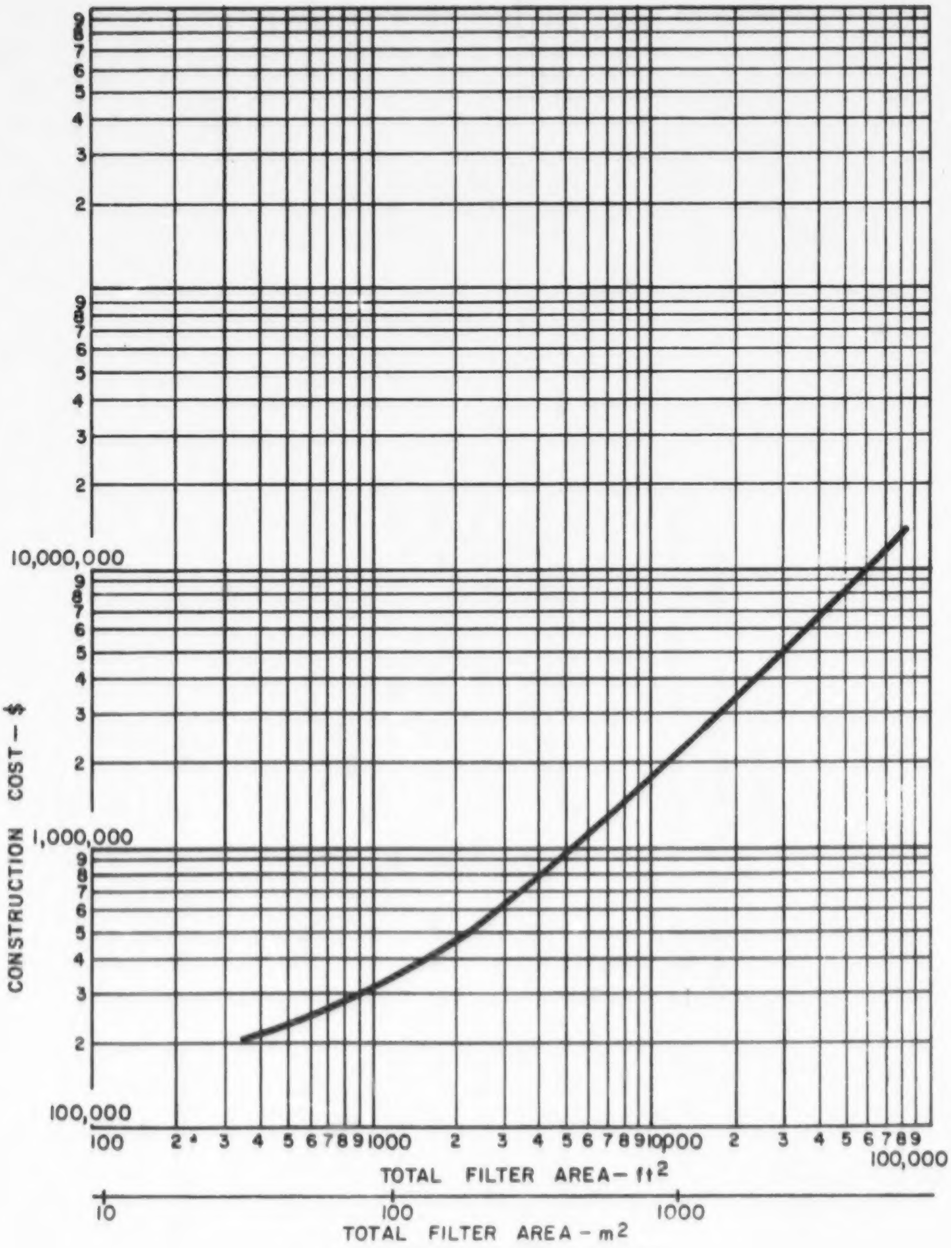
| Plant Flow mgd | Total Filter Area, ft | Filters | | Housing, ft$^2$ |
|---|---|---|---|---|
| | | Number | Area, ft$^2$ | |
| 1 | 360 | 2 | 180 | 1,088 |
| 5 | 1,750 | 2 | 875 | 3,332 |
| 10 | 3,520 | 2 | 1,760 | 6,120 |
| 100 | 35,200 | 20 | 1,760 | 81,600 |
| 200 | 70,400 | 40 | 1,760 | 162,625 |

## Table 91

## Construction Cost

## Continuous Automatic Backwash Filter

| | Plant Flow, mgd | | | | |
|---|---|---|---|---|---|
| | 1 | 5 | 10 | 100 | 200 |
| Excavation and Sitework | $ 280 | 1,330 | 2,500 | 23,000 | 45,000 |
| Manufactured Equipment | 97,450 | 175,000 | 341,000 | 3,075,000 | 6,140,000 |
| Concrete | 10,980 | 27,780 | 46,210 | 472,830 | 936,380 |
| Steel | 4,600 | 11,900 | 19,650 | 182,920 | 362,170 |
| Labor | 23,200 | 53,000 | 100,000 | 773,780 | 1,449,000 |
| Piping and Valves | 10,500 | 14,100 | 21,000 | 55,000 | 110,000 |
| Electrical and Instrumentation | 5,000 | 7,000 | 12,000 | 188,300 | 371,000 |
| Housing | 27,800 | 79,200 | 129,600 | 1,568,000 | 3,057,000 |
| SUBTOTAL | 179,810 | 369,310 | 671,960 | 6,338,830 | 12,520,540 |
| Miscellaneous and Contingency | 26,970 | 55,400 | 100,790 | 950,820 | 1,878,080 |
| TOTAL | $ 206,780 | 424,710 | 772,750 | 7,289,650 | 14,398,620 |



CONSTRUCTION COST
CONTINUOUS AUTOMATIC BACKWASH FILTER

FIGURE 96

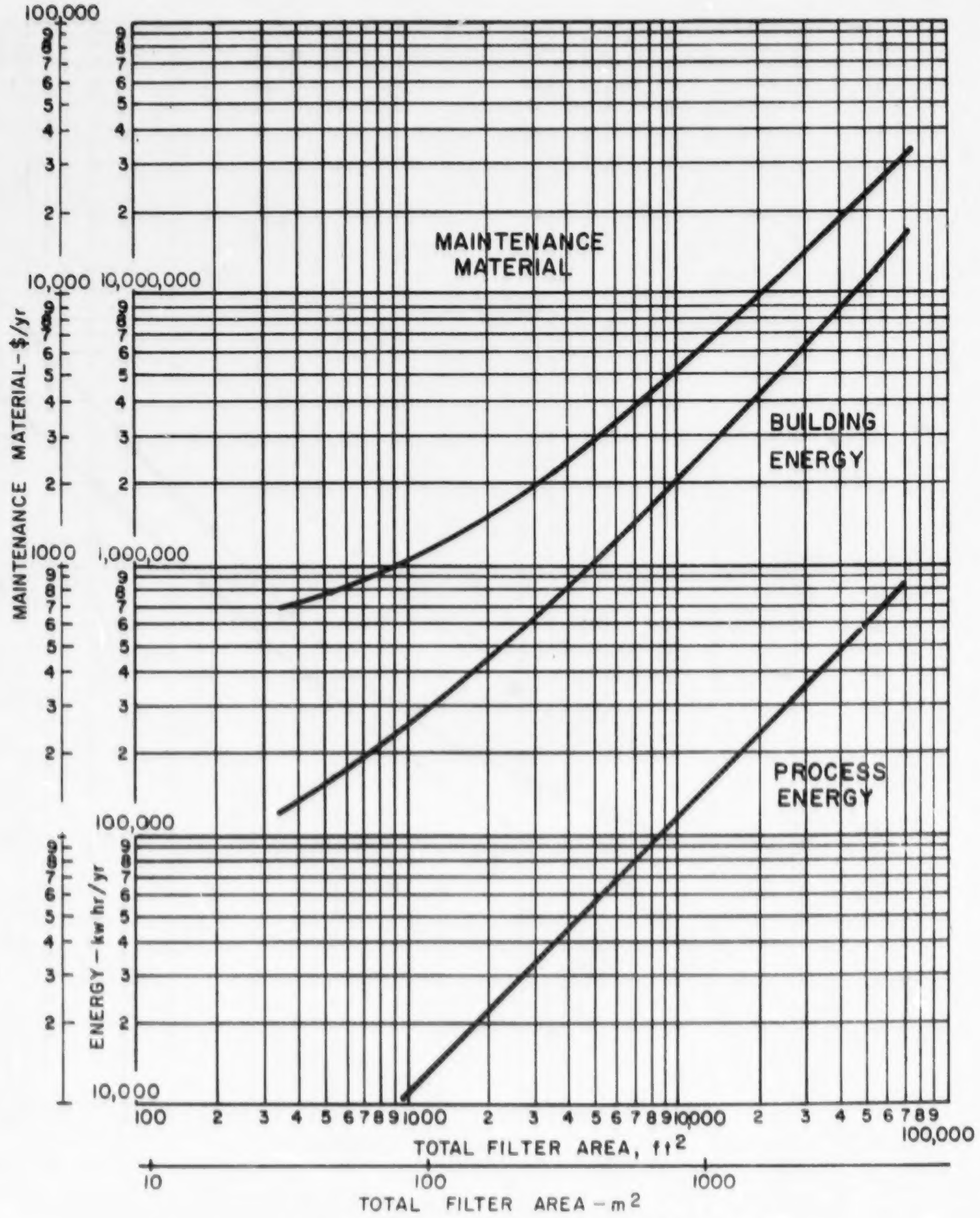
Table 92

Operation and Maintenance Summary

Continuous Automatic Backwash Filter

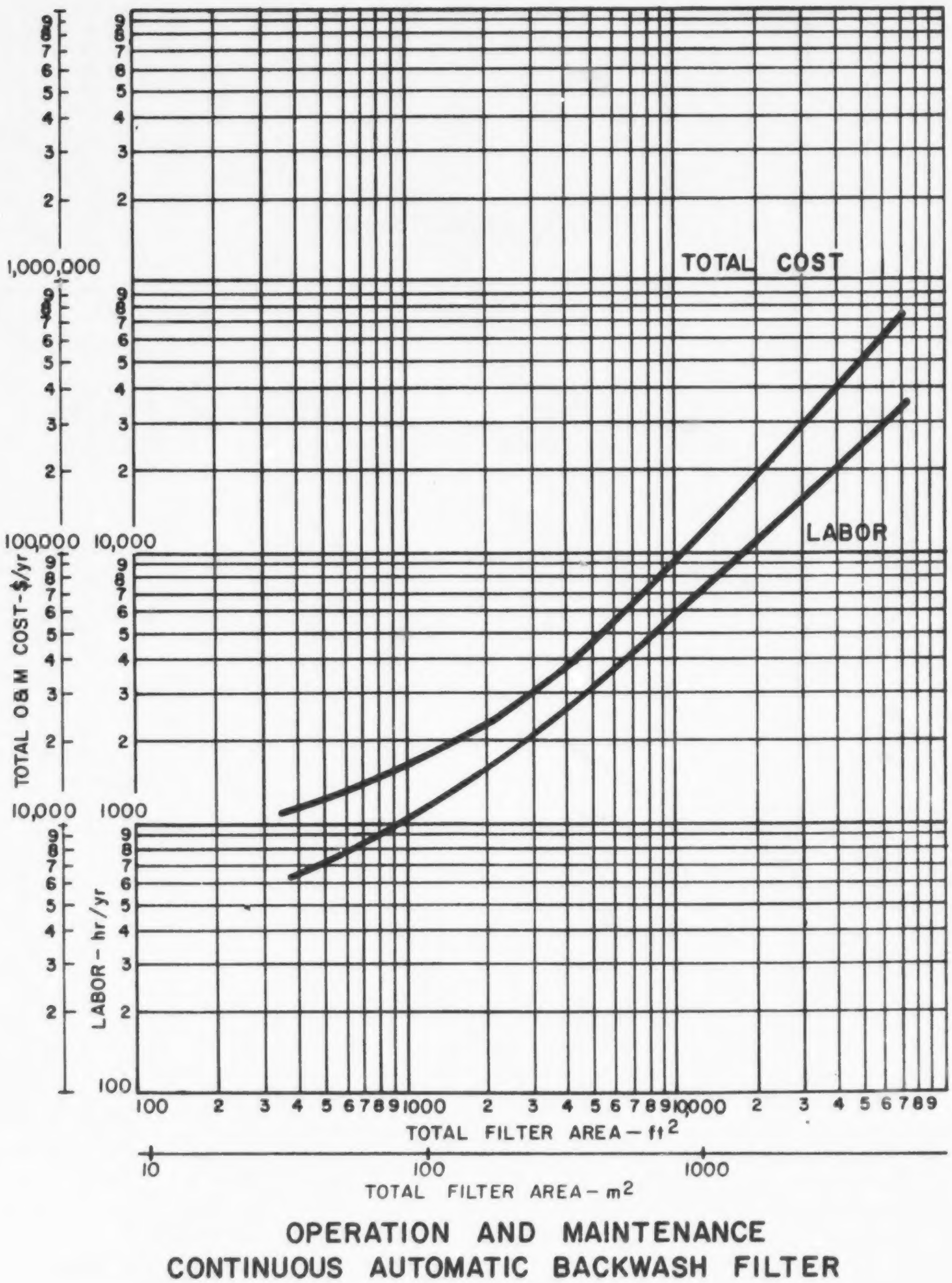
| Plant Flow, mgd | Total Filter Area, $ft^2$ | Energy, kw-hr/yr |  |  | Maintenance Material $/yr | Labor hr/yr | Total Cost* $/yr |
|---|---|---|---|---|---|---|---|
|  |  | Building | Process | Total |  |  |  |
| 1 | 360 | 111,629 | 3,854 | 115,483 | 650 | 728 | 11,394 |
| 5 | 1,750 | 341,863 | 13,624 | 355,487 | 1,400 | 832 | 20,385 |
| 10 | 3,520 | 627,912 | 42,890 | 670,802 | 2,200 | 1,040 | 32,724 |
| 100 | 35,200 | 8,372,160 | 428,900 | 8,801,060 | 19,000 | 10,000 | 383,032 |
| 200 | 70,400 | 16,685,325 | 857,800 | 17,543,125 | 35,000 | 18,000 | 741,294 |

*Calculated using $0.03/kw-hr and $10.00/hr of labor



OPERATION AND MAINTENANCE
CONTINUOUS AUTOMATIC BACKWASH FILTER

FIGURE 97



OPERATION AND MAINTENANCE
CONTINUOUS AUTOMATIC BACKWASH FILTER

FIGURE 98

## VI. EXAMPLE CALCULATION - DIRECT FILTRATION

The following example uses the curves presented in this Interim Report to develop capital and operation and maintenance costs for a direct filtration plant treating a flow of 7 mgd, but designed with a capacity up to 10 mgd. Table 93 presents the design and operating information for this example. The table shows for each required unit process or system, the basic design criteria, the design parameter, and the operating parameter. The design and operating parameters are used with the appropriate cost curves.

TABLE 93

DESIGN CRITERIA
10 MGD DIRECT FILTRATION PLANT

| System and Design Criteria | Design Parameter | Operating Parameter |
|---|---|---|
| Flow Rate - mgd | 10 mgd | 7 mgd |
| Alum Feed System - 30 mg/l operating dose | 104 lb/hr | 73 lb/hr |
| Polymer Feed System - 0.2 mg/l operating dose | 17 lb/day | 12 lb/day |
| Rapid Mix - 30 seconds, G=600 | 464 $ft^3$ | 464 $ft^3$ |
| Flocculation - 20 minutes, G=80 | 18,570 $ft^3$ | 18,570 $ft^3$ |
| Filtration - 5 $gpm/ft^2$, 24 hour filter run | 1,388 $ft^2$ | 1,388 $ft^2$ |
| Filter Media - mixed media | 1,388 $ft^2$ | 1,388 $ft^2$ |
| Surface Wash - 12 hour filter run | 4 @ 350 $ft^2$ each | 4 @ 350 $ft^2$ each |
| Backwash Pumping - 12 hour filter run, 4 filters | 5,250 gpm | 5,250 gpm |

Note: No clearwell is included in this example.

Design criteria presented in Table 93 represent average conditions, but should not be utilized indiscriminantly for any water supply. This report is not intended to serve as a total design manual, but rather to aid in process selection, to illustrate the effect of contaminant concentrations upon overall process sizing, and to provide cost estimating data after the design engineer has selected appropriate design parameters, number of treatment units for each unit process, standby capacity, etc.

Table 94 presents the capital cost and operation/maintenance summary for this example. In Table 94, construction cost and building energy requirements are based upon the design parameter for the process, and thus are

## Table 94

## Direct Filtration Cost Calculation

| Unit Process | Refer to Figure Numbers | Construction Cost | Operation and Maintenance Requirements: Electrical Energy kw-hr/yr Building | Process | Maintenance Material $/year | Labor Hours/year |
|---|---|---|---|---|---|---|
| Alum Feed System - | | | | | | |
| Dry Installed Capacity-104 lb/hr | 48 | 33,000 | 23,090 | | | |
| Feed Rate - 73 lb/hr | 51, 52 | | | 4,900 | 200 | 310 |
| Polymer Feed System | | | | | | |
| Installed Capacity-17 lb/day | 53 | 19,000 | 8,210 | | | |
| Feed Rate - 12 lb/day | 54, 55 | | | 17,300 | 270 | 200 |
| Rapid Mix-G=600, Vol=464 $ft^3$ | 56 | 16,000 | 0 | | | |
| | 57, 58 | | | 47,240 | 30 | 470 |
| Flocculation - G=70 | | | | | | |
| Horizontal Paddle, Volume = | 59 | 150,000 | 0 | | | |
| 18,570 $ft^3$ | 61, 62 | | | 57,000 | 1,400 | 200 |
| Filtration | 63 | 500,000 | 270,000 | | | |
| Total Filter Area=1,388 $ft^2$ | 64, 65 | | | 0 | 7,050 | 2,500 |
| Filter Media | | | | | | |
| 1,388 $ft^2$ | 66 | 45,600 | 0 | 0 | 0 | 0 |
| Surface Wash | 67 | 73,720 | 0 | | 150 | 120 |
| Four 350 $ft^2$ filters | 68, 69 | | | 20,440 | | |
| Backwash Pumping | 70 | 80,000 | 0 | | | |
| Installed Capacity=5,250 gpm | 71, 72 | | | 49,640 | 180 | 160 |
| 10 minute wash, 4 filters | | | | | | |
| SUBTOTALS | | 917,320 | 301,300 | 196,520 | 9,280 | 3,960 |
| Sitework, interface piping roads at 5% | | 45,870 | | | | |
| Subsurface Considerations | | 0 | | | | |
| Standby Power | | 0 | | | | |
| TOTAL CONSTRUCTION COST | | 963,190 | | | | |
| General Contractors Overhead and Profit | 99 | 120,400 | | | | |
| SUBTOTAL | | 1,083,590 | | | | |
| Engineering @ 10% | | 108,360 | | | | |
| SUBTOTAL | | 1,191,950 | | | | |
| Land, 3 acres @ $2,000/acre | | 6,000 | | | | |
| Legal, Fiscal and Administrative | 101 | 20,000 | | | | |
| Interest during construction-7% | 103 | 60,000 | | | | |
| TOTAL CAPITAL COST | | 1,277,950 | | | | |

independent of the actual flow through the process. However, process energy, maintenance material, and labor requirements are all based upon the operating variable for the process, and therefore, vary with the flow through the process. For example, the alum feed system is sized for a feed capacity of 104 pounds per hour, yet is only operated in the example at 73 pounds per hour. Construction costs and building related energy are then obtained from the cost curves using the design parameter (104 pounds per hour), while operation/maintenance costs other than building related energy are obtained from the cost curves using the operating parameter (73 pounds per hour). This approach represents, in our opinion, the most accurate method for use of the curves when a process operates at less than design capacity. Other approaches may be used however, simply by varying the operating parameter.

The sum of the construction costs for the individual unit processes yields a subtotal which is the basis for a number of special costs related more to the aggregate cost than the cost of the individual unit processes. These special costs include: (1) special sitework, landscaping, roads, and interface piping between processes, (2) special subsurface considerations, and (3) standby power. The special costs can vary widely, depending upon the site available, the design engineer's preference, and regulatory agency requirements. The computer program being developed as a part of this Project will allow percentages and/or costs to be used for these special costs. Adding these special costs to the aggregate cost of the unit processes gives the total construction cost.

To the total construction cost, the following costs must be added: (1) general contractors overhead and profit, (2) engineering, (3) land, (4) legal, fiscal, and administrative, and (5) interest during construction. Curves for these costs, with the exception of engineering cost and land are presented in Figures 99 to 103. A curve for engineering cost is not included as the cost can vary widely depending on the need for the complexity of preliminary studies, time delays, the size of the project, and any construction related inspection and engineering design activities. The computer program being developed as a part of this Project will allow a variable input percentage for engineering, and for land, a variable cost and acreage requirement.

Table 95 presents the calculation of annual cost and cost per 1,000 gallons treated. This calculation involves a number of variables, such as amortization percentage and period, labor rate, power rates, and unit cost for chemicals. The variables used in Table 95 are representative of United States averages, but may vary significantly between geographic areas. The computer program being developed will allow variable input for each of these rates or unit costs.

## TABLE 95

## ANNUAL COST FOR DIRECT FILTRATION EXAMPLE

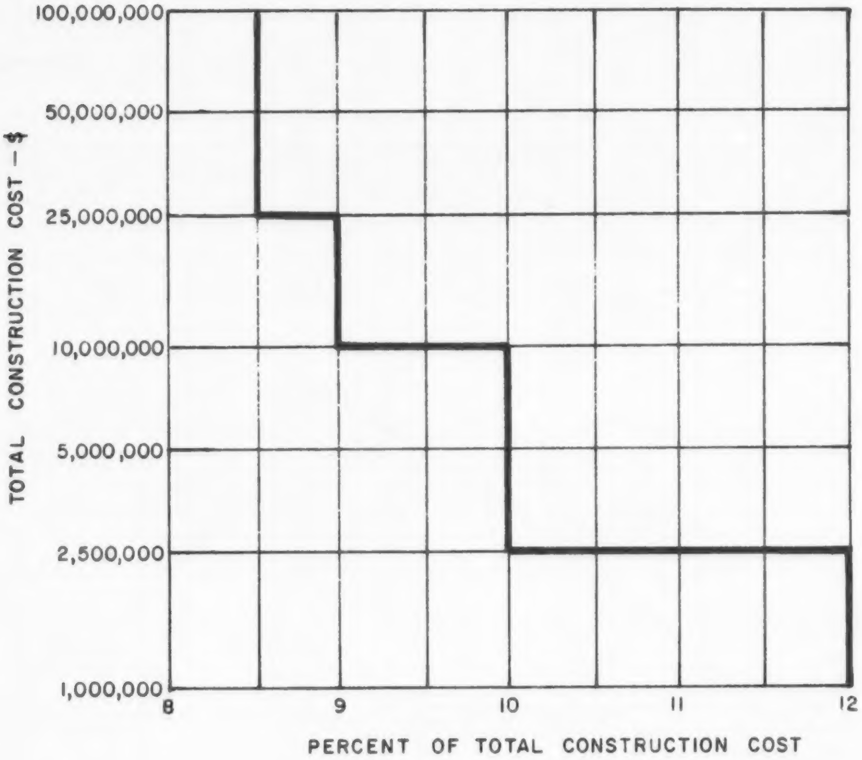
Total Annual Costs:

| | |
|---|---|
| Amortized Capital @ 7%, 20 years | $120,630/year |
| Labor, 3,960 hours @ $10/hr (total labor costs including fringes and benefits) | $ 39,600/year |
| Electricity, 497,820 kwh @ $0.03 | $ 14,930/year |
| Fuel | $ 0/year |
| Maintenance Material | $ 9,280/year |
| Chemicals, Alum, 320 tons/year @ $70/ton<br>Polymer, 4,380 lbs/yr @ $2/lb | $ 31,160/year |
| TOTAL ANNUAL COST | $215,600/year |

$$\text{Cents per 1,000 gallons treated} = \frac{215{,}600 \times 0.1}{365 \times 7 \text{ mgd}}$$

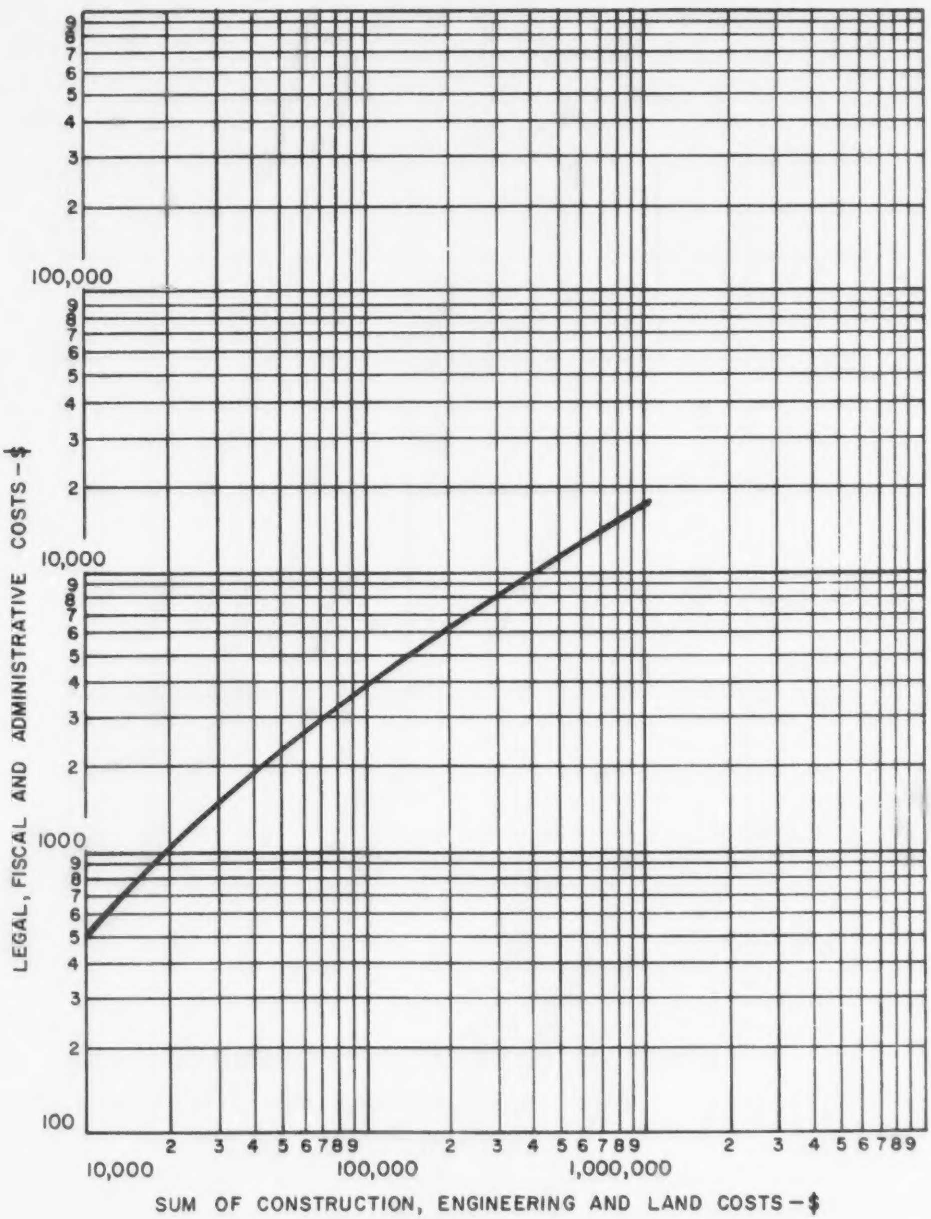
$$= 8.43\ \text{¢}/1{,}000 \text{ gallons treated}$$

Note: Does not include clearwell costs or ultimate sludge disposal costs.



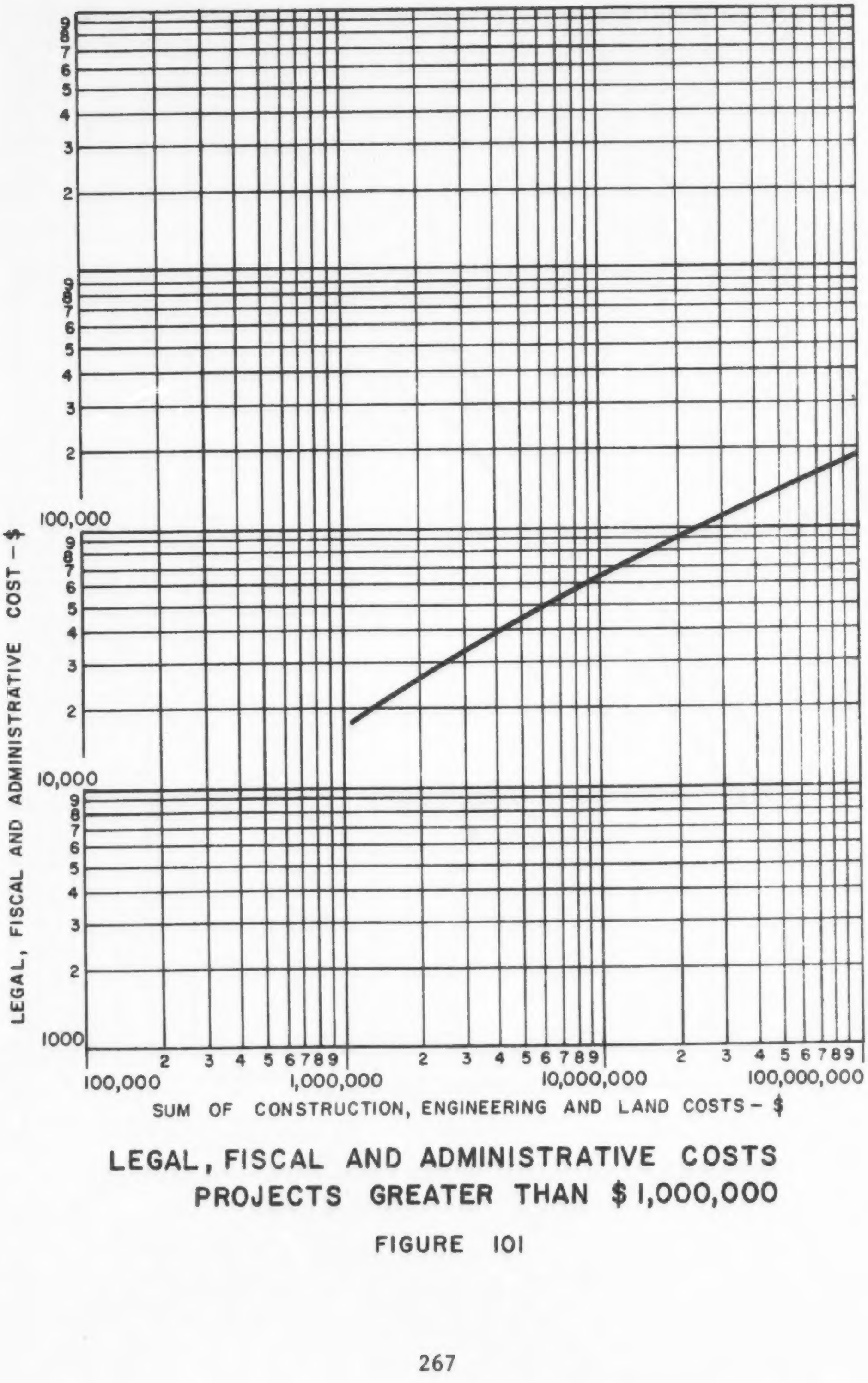
GENERAL CONTRACTOR OVERHEAD AND FEE PERCENTAGE VS TOTAL CONSTRUCTION COST

FIGURE 99



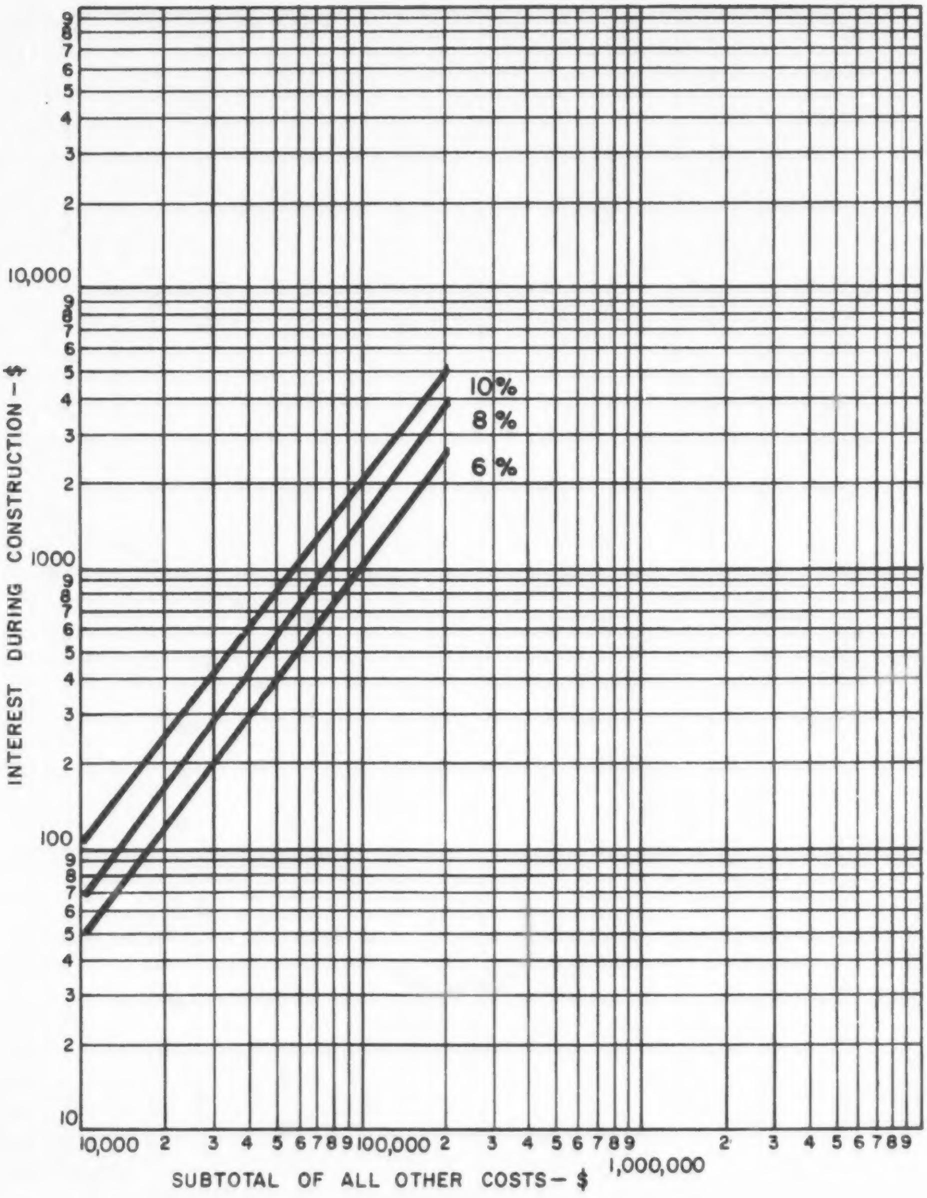
LEGAL, FISCAL AND ADMINISTRATIVE COSTS
PROJECTS LESS THAN $1,000,000

FIGURE 100



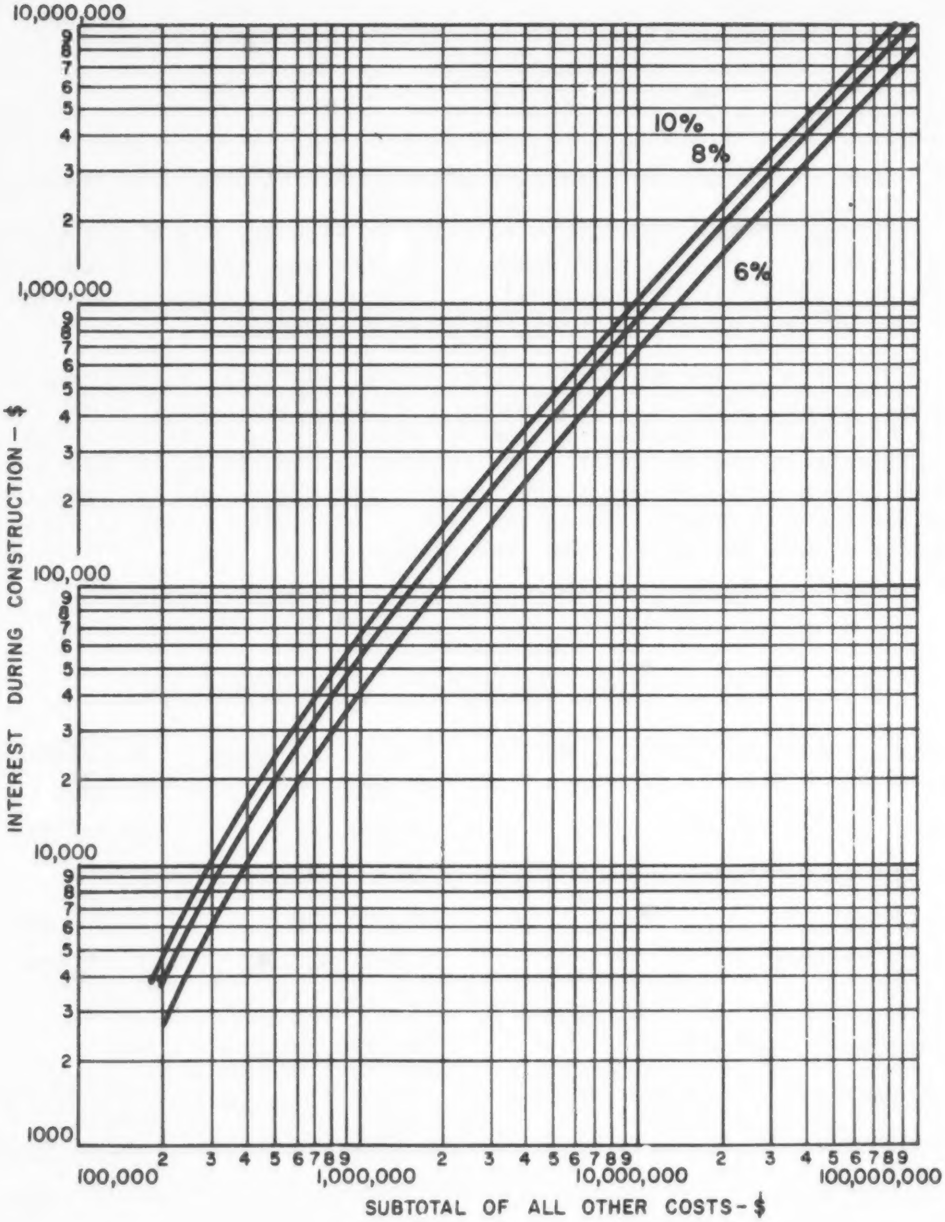
LEGAL, FISCAL AND ADMINISTRATIVE COSTS
PROJECTS GREATER THAN $1,000,000

FIGURE 101



INTEREST DURING CONSTRUCTION - PROJECTS LESS THAN $ 200,000

FIGURE 102



INTEREST DURING CONSTRUCTION
PROJECTS GREATER THAN $ 200,000

FIGURE 103

## VII. EXAMPLE CALCULATION - PRESSURE GRANULAR ACTIVATED CARBON PLANT

This example uses the curves included in this Interim Report to develop capital and operation and maintenance costs for granular activated carbon treatment using pressure contactors. In the example, the plant design capacity is 15 mgd and the system is operating at full capacity.

Table 96 presents the design criteria and operating information for this example. These design criteria represent hypothetical conditions, and should not be utilized indiscriminately for any water supply. Before design of facilities is initiated, pilot plant studies are necessary to determine the optimum carbon contactor empty bed contact time (EBCT) and regeneration frequency for the carbon. These two factors will have a very significant influence on the cost of a given size system.

TABLE 96

DESIGN CRITERIA

15 MGD PRESSURE GRANULAR ACTIVATED CARBON PLANT

| System Description & Design Criteria | Design Parameter | Operating Parameter |
|---|---|---|
| Flow | 15 mgd | 15 mgd |
| Required Carbon Volume[1] | 20,889 $ft^3$ | 20,889 $ft^3$ |
| Number Contactors[2] | 18 | 18 |
| Supply Pumping[3] | 10,500 gpm | 10,500 gpm |
| Backwash Pumping[4] | 1,360 gpm | 1,360 gpm |
| Required Multiple Hearth Furnace Area[5] | 245 $ft^2$ | 245 $ft^2$ |
| Initial Carbon Charge[6] | 626,670 lbs | -- |
| Makeup Carbon - 7% per regeneration | -- | 263,201 lbs |

[1] Determined at assumed EBCT of 15 minutes with application rate of 5 $gpm/ft^2$ and a 10 foot carbon depth.

[2] Assume 12' Ø units @ 113 $ft^2$/unit

[3] Operating head 35 feet

[4] One backwash per day for 10 minute duration

[5] Furnace area based upon regeneration every two months, a carbon density of 30 $lbs/ft^3$, a hearth loading of 70 $lbs/ft^2$/day and 40 percent down time

[6] Based upon density of 30 $lbs/ft^3$

Table 97 presents the capital cost and operation and maintenance requirements for each of the unit processes required in this example. The figure numbers for the curves which were used to develop these costs and operation and maintenance requirements are also shown in Table 97. The one exception is for supply pumping, a curve which was unavailable in final form at the time this Interim Report was prepared.

The sum of the construction costs for the individual unit processes shown in Table 97 yields a subtotal cost which is the basis for a number of special costs more appropriately related to the subtotal cost than to the construction cost of each individual unit processes. These special costs include: (1) special sitework, landscaping, roads, and interface piping between processes, (2) special subsurface considerations, and (3) standby power. The special costs can vary widely, depending upon the site, the design engineer's preference, and regulatory agency requirements. Adding these special costs to the aggregate cost of the unit processes gives the total construction cost.

To arrive at the total capital cost, the following costs must be added to the total construction cost: (1) general contractor's overhead and profit, (2) engineering, (3) land, (4) legal, fiscal and administrative, and (5) interest during construction. Curves for these costs, with the exception of engineering cost and land are presented in Figures 99 to 103. A curve for engineering cost is not included as the cost will vary widely, depending on the need for preliminary studies, time delays, the size and complexity of the project, and any construction related inspection and engineering design activities.

Table 98 presents a calculation of total annual cost and cost per 1,000 gallons treated. This calculation involves a number of variables such as amortization rate and period, labor rate including fringes and benefits, electrical rates, and natural gas rates. The variables used in Table 3 are representative of United States averages, but may vary significantly between geographical areas.

### Table 97

### Pressure Granular Activated Carbon Cost Calculation

| Unit Process | Refer to Figure Numbers | Construction Cost | Electrical Energy kw-hr Building | Electrical Energy kw-hr Process | Natural Gas scf/yr | Maintenance Material $/year | Labor hr/yr |
|---|---|---|---|---|---|---|---|
| Pressure Carbon Contactors<br>Volume = 20,889 $ft^3$<br>Surface Area = 2,090 $ft^2$ | 11<br>12, 13 | 1,600,000 | 600,000 | 11,000 | | 9,500 | 3,900 |
| Initial Carbon Charge, 626,670 lbs | 27 | 370,000 | | | | | |
| Supply Pumping - 10,500 gpm | * | 160,000 | 0 | 963,270 | | 2,500 | 800 |
| Backwash Pumping - 1,360 gpm, one ten minute wash/day/contactor | 70 | 45,000 | 0 | ** | | ** | ** |
| Multiple Hearth Carbon Regeneration, 245 $ft^2$ | 23<br>24, 25, 26 | 1,200,000 | 20,000 | 360,000*** | 22,800,000*** | 4,800*** | 2,760 |
| Makeup Carbon - 263,201 lb/yr | 27 | -- | -- | -- | -- | 160,000 | -- |
| SUBTOTALS | | 3,375,000 | 620,000 | 1,334,270 | 22,800,000 | 176,800 | 7,460 |
| Sitework, interface piping, roads at 5% | | 168,750 | | | | | |
| Subsurface Considerations | | 0 | | | | | |
| Standby Power | | 0 | | | | | |
| TOTAL CONSTRUCTION COST | | 3,543,750 | | | | | |
| General Contractors Overhead and Profit | 99 | 354,380 | | | | | |
| SUBTOTAL | | 3,898,130 | | | | | |
| Engineering @ 10% | | 389,810 | | | | | |
| SUBTOTAL | | 4,287,940 | | | | | |
| Land, 6 acres @ $2,000/acre | | 12,000 | | | | | |
| Legal Fiscal and Administrative | 101 | 41,000 | | | | | |
| Interest during construction - 8% | 103 | 330,000 | | | | | |
| TOTAL CAPITAL COST | | 4,670,940 | | | | | |

*These curves were unavailable in final form at the time the Interim Report was prepared. The curves will be included in the Final Report.

**Included in the pressure contactor costs.

***Value for 245 $ft^2$ (0.6) to account for 60% down time.

## Table 98

## Annual Cost for Granular Activated Carbon Plant Example

Total Annual Costs:

| | |
|---|---|
| Amortized Capital @ 7%, 20 years | \$ 440,890/yr |
| Labor, 7,460 hours @ \$10/yr (total labor costs including fringes and benefits) | \$ 74,600/yr |
| Electricity, 1,954,270 kwh @ \$0.03 | \$ 58,630/yr |
| Natural Gas 22,800,000 scf @ \$0.0013 | \$ 29,640/yr |
| Maintenance Material | \$ 176,800/yr |
| TOTAL ANNUAL COST | \$ 780,560/yr |

$$\text{Cents per 1,000 gallons treated} = \frac{\$780{,}560/\text{yr}\ (0.1)}{365 \times 15\ \text{mgd}}$$

$$= 14.26¢/1{,}000\ \text{gallons treated}$$

# APPENDIX A

# GEOGRAPHICAL INFLUENCE UPON BUILDING RELATED ENERGY

Overall building related energy requirements are greatly influenced by the geographical location. Those components which show strong geographical influence are heating and cooling, whole lighting and ventilation are relatively constant in different geographic areas. A lighting requirement of 2 watts/square foot is adequate for most enclosed water treatment processes or equipment. This is equivalent to 17.5 kw-hr/ft$^2$/yr. Ventilating requirements are also relatively constant, a 2.2 kw-hr/ft$^2$/yr, based on six air changes per hour.

An analysis was conducted of heating and cooling requirements for each of the 21 cities included in the ENR Indices. This analysis was done for a building module of 20' x 40' x 14', an average winter indoor temperature of 68°F and an average summer indoor temperature of 75°F. Although it certainly would not be true in many situations, electrical energy was assumed for heating in each area. The results, expressed in terms of kw-hr/ft$^2$/yr are shown in Table 1, along with the ventilation and lighting requirements.

As can be seen, building related energy requirements range from a low of 25.8 kw-hr/ft$^2$ in Miami to a high of 219.8 kw-hr/ft$^2$ in Minneapolis. The 21 city average was 102.6 kw-hr/ft$^2$, and this value was used to develop the total operation/maintenance cost curves included in this Report.

# TABLE 1
## GEOGRAPHICAL INFLUENCE UPON BUILDING RELATED ENERGY

| | Electrical Energy - kw-hr/ft$^2$/yr | | | | |
|---|---|---|---|---|---|
| City | Lighting | Ventilation | Heating | Cooling | TOTAL |
| Seattle | 17.5 | 2.2 | 59.4 | 0.2 | 79.3 |
| Salt Lake City | 17.5 | 2.2 | 144.0 | 0.8 | 164.5 |
| Omaha | 17.5 | 2.2 | 157.3 | 0.9 | 177.9 |
| Minneapolis | 17.5 | 2.2 | 199.4 | 0.7 | 219.8 |
| Chicago | 17.5 | 2.2 | 146.4 | 0.8 | 166.9 |
| New York | 17.5 | 2.2 | 90.3 | 0.7 | 110.7 |
| Boston | 17.5 | 2.2 | 104.4 | 0.4 | 124.5 |
| San Francisco | 17.5 | 2.2 | 40.5 | 0.5 | 60.7 |
| Denver | 17.5 | 2.2 | 149.5 | 1.6 | 170.8 |
| St. Louis | 17.5 | 2.2 | 116.6 | 2.4 | 138.7 |
| Las Vegas | 17.5 | 2.2 | 36.3 | 2.4 | 58.4 |
| Richmond, Va. | 17.5 | 2.2 | 71.6 | 1.6 | 92.9 |
| Nashville | 17.5 | 2.2 | 70.6 | 2.0 | 92.3 |
| Washington, D.C. | 17.5 | 2.2 | 78.3 | 1.6 | 99.6 |
| Los Angeles | 17.5 | 2.2 | 27.7 | 0.5 | 47.9 |
| Pheonix | 17.5 | 2.2 | 23.7 | 2.4 | 45.8 |
| Albuquerque | 17.5 | 2.2 | 80.6 | 1.2 | 101.5 |
| Dallas | 17.5 | 2.2 | 43.8 | 5.6 | 69.1 |
| Tampa | 17.5 | 2.2 | 9.2 | 3.2 | 32.1 |
| Atlanta | 17.5 | 2.2 | 54.9 | 1.5 | 76.1 |
| Miami | 17.5 | 2.2 | 2.9 | 3.2 | 25.8 |
| Averages: | 17.5 | 2.2 | 81.3 | 1.6 | 102.6 |

NOTE: Building module used was 20' x 40' x 14', with a winter inside design temperature of 68°F, a summer inside design temperature of 75°F and a ventilation rate of 6 changes per hour.

## APPENDIX B

## ESTIMATING COSTS FOR GRANULAR ACTIVATED CARBON SYSTEMS IN WATER PURIFICATION BASED ON EXPERIENCE IN WASTEWATER TREATMENT

### INTRODUCTION

Because the use of granular activated carbon (GAC) is relatively new in the purification of potable water, there is a rather limited amount of cost data available from actual plant operations. Fortunately, however, GAC has been used since 1965 for the adsorption of organics from wastewater. Complete, detailed, reliable cost data are available on constructing, operating, and maintaining complete GAC wastewater treatment systems including carbon contact, regeneration, and transport. These data are available from a number of sources and for a variety of plant capacities.

There are differences in the use of GAC for water purification and wastewater treatment, however, and these differences will influence cost. Some of the differences are obvious, but others are less apparent. However, a sanitary engineer who is informed and experienced in both fields as well as in cost estimating can use the cost experience accumulated in wastewater operations to estimate GAC costs for water purification quite readily, and with the same degree of accuracy (± 15%) attendant to preliminary estimates for other water treatment processes.

### GAC SYSTEM COMPONENTS

Systems utilizing granular carbon are rather simple. In general, they provide for: (1) contact between the carbon and the water to be treated for the length of time required to obtain the necessary removal of organics, (2) regeneration or replacement of spent carbon, and (3) transport of makeup or regenerated carbon into the contactors and of spent carbon from the contactors to regeneration or hauling facilities.

Selecting Carbon and Plant Design Criteria. Pilot plant tests are a mandatory prelude to carbon selection and plant design for both water and wastewater treatment projects. Pilot column tests make it possible to: (1) select the best carbon for the specific purpose based on performance; (2) determine the required contact time; (3) establish the required carbon dosage, which will determine the capacity of the carbon regeneration furnace or the necessary carbon replacement costs; and (4) determine the effects of variations in influent water quality.

One of the principal differences in costs for GAC treatment between water and wastewater will be the more frequent regeneration required in water purification due to earlier breakthrough of the organics of concern. In wastewater treatment, GAC may be expected to adsorb 0.30 to 0.55 pounds of COD per pound of carbon before the carbon is exhausted. In water treatment, the organics of concern may breakthrough at carbon loadings much lower than those which are obtained in wastewater treatment. THE ALLOWABLE CARBON LOADING OR CARBON DOSAGE AND THE NEEDED REGENERATION CAPACITY MUST BE DETERMINED FROM PILOT PLANT TEST RESULTS. These factors cannot be estimated from wastewater data. Therefore, costs taken from wastewater cost curves which are plots of flow in mgd versus cost (capital cost or O & M costs) cannot be applied directly to water treatment. Allowance must be made in the capital costs for the greater regeneration capacity needed, and in the O & M costs for the greater amount of carbon to be regenerated or replaced.

Preliminary indications are that the lightly-loaded carbons resulting from water treatment can be more rapidly and easily reactivated than those from wastewater treatment, so that proportionally less furnace capacity will be needed. However, the regeneration characteristics of carbon saturated with organics adsorbed during water purification are not well established at this time. Until these characteristics are better understood, it appears prudent to use the regeneration characteristics of GAC which has been saturated with organics adsorbed from wastewater as a guide to regeneration capacity required for water treatment. If such time and temperature requirements per pound of carbon to be regenerated are used, regeneration equipment may be larger and more expensive than necessary, but the amount of such cost is not great, and some factor of safety in regeneration capacity would be obtained.

Selection of the general type of carbon contactor to be used for a particular water treatment plant application may be based on several considerations indicating the judgement and preference of the engineering designer. The choice generally would be made from three types of downflow vessels:

1. Deep-bed, factory-fabricated, steel pressure vessels of 12-foot maximum diameter. These vessels might be used over a range of carbon volumes from 2,000 to 50,000 cubic feet.

2. Shallow-bed, reinforced concrete, gravity filter-type boxes may be used for carbon volumes ranging from 1,000 to 200,000 cubic feet. Shallow beds probably will be used only when long service cycles between carbon regenerations can be expected, based on pilot plant test results.

3. Deep-bed, site-fabricated, large (20 to 30 feet) diameter, open steel, gravity tanks may be used for carbon volumes ranging from 6,000 to 200,000 cubic feet, or larger.

These ranges overlap, and the designer may very well make the final selection based on local factors, other than total capacity, which affect efficiency and cost.

GAC Contactors. The advanced wastewater treatment (AWT) experience with GAC contactors may be applied to water purification if some differences in requirements are taken into account. The required contact time must be determined from pilot plant test results. Contactors may be designed for a downflow or upflow mode of operation. Upflow packed beds or expanded beds provide maximum carbon efficiency through the use of countercurrent flow principles. However, upflow beds can be used only when followed by filtration due to the leakage of some carbon fines in the effluent. Downflow beds probably will be used in most municipal water treatment applications. Single beds or two beds in series may be used. Open gravity beds or closed pressure vessels may be used. Structures may be coal-tar epoxy coated steel or reinforced concrete. In general, small plants will use steel, and large plants may use steel or reinforced concrete.

In some instances where GAC has been used in existing water filtration plants, sand in rapid filters has been replaced with GAC. In situations where GAC regeneration or replacement cycles are exceptionally long (several months or years), as may be the case in taste and odor removal, this may be a solution. However, with the short cycles anticipated for most organics, conventional concrete box style filter beds are not well suited to GAC contact. There principal drawbacks are the shallow bed depths and the difficulty of moving carbon in and out of the beds. Deeper beds, or contactors with greater aspect ratios of depth to area, provide much greater economy in capital costs. The contactor cost for the needed volume of carbon is much less. Carbon can be moved in water slurry from contactors with conical bottoms easily and quickly and with virtually no labor. Flat-bottomed filters which require labor to move the carbon, unnecessarily add greatly to carbon transport costs. For most, if not all, GAC installations for trihalomethane (THM) removal, precursor organic removal, or synthetic organic removal, the use of conventional filter boxes will not be a permanent solution and specially designed GAC contactors should be installed. Contactors should be equipped with flow measuring devices. Seperate GAC contactors are especially advantageous where GAC treatment is required only part of the time during certain seasons, because they then can be used only when needed and bypassed when not needed, thus saving unnecessary exhaustion and regeneration of GAC. In summary, tremendous cost savings can be realized in GAC treatment of water through proper selection and design of the carbon contactors.

GAC Replacement or Regeneration. Spent carbon may be removed from contactors and replaced with virgin carbon, or it may be regenerated either on-site or off-site. The most economical mode depends upon the quantities of GAC involved and the effective service life of the carbon. For large plants and large volumes of GAC, on-site regeneration is the answer. Only in small plants, or in large plants with service cycles of several months, will carbon replacement or off-site regeneration be economical.

Carbon may be thermally regenerated to full virgin activity. However, carbon losses may be excessive under these conditions. Experience in industrial and wastewater treatment indicates that carbon losses can be minimized (held to 8 to 10 percent per cycle) if the GAC activity of regenerated carbon as indicated by the Iodine Number, is held at about 90 percent of the virgin activity. For removal of certain organics, there may be no decrease in removal despite a 10 percent drop in Iodine Number.

Thermal Regeneration Equipment. GAC may be reactivated in a multiple-hearth furnace, a fluidized bed furnace, a rotary kiln, or an electric infrared furnace. Spent GAC is drained dry (40 percent moisture content) in a screen-equipped tank or in a dewatering screw before introduction to the regeneration furnace. Dewatered carbon is usually transported by a screw conveyor. Following thermal regeneration, the GAC is cooled in a quench tank. The water-carbon slurry may then be transported by means of diaphragm slurry pumps, eductors, or a blow-tank. The regenerated carbon may contain fines produced during conveyance, and these fines should be removed in a water tank or in the contactor. Maximum furnace temperatures and time of retention in the furnace are determined by the amount (pounds of organics per pound of carbon) and nature (molecular weight) of the organics adsorbed.

Off-gases from carbon regeneration present no air pollution problems provided they are properly scrubbed, or, in some cases, passed through an afterburner (for odor control) and then scrubbed.

Required Furnace Capacity. The principal cost differences between GAC treatment of water and wastewater lie in the capital cost of the furnace and in the O & M costs for the quantity of carbon to be regenerated. As already discussed, the cost of regeneration per pound of carbon may be less for carbons used in water treatment due to the greater volatility of the organics adsorbed, but a prudent approach to use at the present time is to assume that the cost of regeneration per pound of carbon is the same for GAC used in treating water and wastewater.

Also, as previously mentioned, the pounds of organics adsorbed on a pound of carbon at the point of breakthrough may be quite different for water and wastewater. Usually the loading will be much less for water treatment carbons. TO ACCURATELY ESTIMATE GAC COSTS FOR WATER PURIFICATION IT IS ESSENTIAL TO TAKE INTO ACCOUNT THE DIFFERENCE IN THE AMOUNT OF ORGANICS ADSORBED AS COMPARED TO THOSE ADSORBED IN AWT. To fail to take this important difference into account could lead to erroneous estimates of cost, and the estimated cost differences could be substantial. To repeat, it is not possible to use GAC cost curves for AWT based on mgd throughput or plant capacity to obtain costs for water treatment. Differences in regeneration requirements must be taken into account.

Carbon Transport and GAC Process Auxiliaries. There can be tremendous differences in O & M costs for GAC systems depending upon the method selected for carbon transport. Transport of GAC in water slurry by gravity or use of water pressure is simple, easy, inexpensive, rapid, and uses very little labor. Moving dry or dewatered carbon manually or with mechanical means involving labor can be very difficult, time consuming, and costly. The proper use of conical bottoms in carbon contactors, dewatering bins, storage bins, wash tanks, and the like can minimize GAC handling costs. Efforts to use existing (or new) flat-bottomed structures requiring operator or other labor to more the carbon can be costly.

## SOURCES OF COST AND DESIGN DATA FOR GAC SYSTEMS

General. There are three main sources of cost information and organic adsorption data needed to prepare cost estimates for GAC systems for production of drinking water. These are the: (1) EPA publications, particularly those of recent research at the Cincinnati laboratories, (2) articles concerning the experience with GAC in AWT, and (3) papers concerning the use of GAC in water filtration plants.

EPA Publications. Pertinent publications of interest are:

1. Clark, Robert M., et al., "The Cost of Removing Chloroform and Other Trihalomethanes From Drinking Water Supplies", EPA 600/1-77-008, March, 1977.
2. Symons, James M., "Interim Treatment Guide for Controlling Organic Contaminants in Drinking Water Using Granular Activated Carbon", EPA Water Supply Research Division, Cincinnati, January, 1978.
3. "Advanced Wastewater Treatment as Practiced at South Tahoe", EPA 17010ELQ08/71, August, 1971.

Reference No. 2 on page 108 gives an example of the method of converting carbon dosage requirements for water purification into regeneration requirements and costs, using carbon dosage requirements obtained from the results of pilot plant work. This example includes capital and O & M costs.

AWT Cost Experience. Good cost data is available from operating installations at: (1) The South Tahoe Public Utility District, South Lake Tahoe, California (13 years), (2) the Orange County Water District, Fountain Valley, California (4 years), and (3) the Upper Occoquan Sewage Authority, Manassas Park, Virginia (capital cost data only - plant not yet in operation).

The South Tahoe data is summarized in two books: (1) Culp, R.L. and Culp, G.L., "Advanced Wastewater Treatment", Van Nostrand Reinhold, New York, 1971, and (2) Culp, Wesner, Culp "Handbook of Advanced Wastewater Treatment", Van Nostrand Reinhold, New York, 1978.

GAC Experience in Potable Water Treatment. The experience with 12 integrated filtration-adsorption units is summarized on pages 239-247 of "New Concepts in Water Purification", Culp and Culp, Van Nostrand Reinhold, New York, 1974 (see Table 1).

### TABLE 1

### GRANULAR CARBON INSTALLATIONS IN MUNICIPAL WATER PLANTS IN THE UNITED STATES

| Water Plant Location | Year Installed | Size of Plant (mgd) | Flow Rate (gpm ft$^3$) | Carbon Bed Depth |
|---|---|---|---|---|
| AWWS Co., Hopewell, Virginia | 1961 | 3.0 | 2.0 | 24 in. |
| Nitro, West Virginia | 1966 | 10.0 | 1.5-2.0 | 30 in. |
| Montecito Co. Water District Santa Barbara, California | 1963 | 1.5 | 6 | 12 ft. |
| Del City, Oklahoma | 1967 | 5.25 | 2 | 36 in. |
| Somerset, Massachusetts | 1968 | 4.5 | 2 | 11 in. |
| Pawtucket, Rhode Island | 1969 | 24 | 2 | 18 in. |
| Lawrence, Massachusetts | 1969 | 10 | 2 | 24 in.<br>30 in. |
| Piqua, Ohio | 1969 | 8 | 2 | 18 in. |
| Bartlesville, Oklahoma | 1970 | 4.5 | 2 | 24 in. |
| Granite City, Illinois | 1971 | 7 | 1.4 | 18 in. |
| Winchester, Kentucky | 1970 | 1.5 | 2 | 24 in. |
| Mt. Clemens, Michigan | 1968 | 7 | 1.7 | 24 in. |

**Industrial and Miscellaneous Municipal Carbon Regeneration Furnace Installations**. Some cost data is also available from the following carbon furnace installations:

## CARBON FURNACE INSTALLATIONS

| Installation | Date | Use | |
|---|---|---|---|
| Hollytex Carpet Mills, PA | 1969 | Dye Wastewater | |
| BP Oil, N.J. | 1971 | Wastewater, | Industrial |
| Stepan Chemical Co., N.J. | 1972 | " | " |
| Hercules, Mississippi | 1972 | " | " |
| Amerada Hess, N.J. | 1973 | " | " |
| American Aniline, PA | 1973 | " | " |
| American Cyanimid, N.J. | 1977 | " | " |
| Esso Research | 1973 | " | " |
| Republic Steel Corp. | 1974 | " | " |
| Colorado Springs, CO | 1969 | " | Municipal |
| Rocky River, OH | 1972 | " | " |
| Derry Township, PA | 1974 | " | " |
| Vallejo, CA | 1974 | " | " |
| Santa Clara V.W.D. Palo Alto, CA | 1975 | " | " |
| Tahoe-Truckee San. Dist., CA | 1976 | " | " |
| No. Towanda, N.Y. | 1976 | " | " |
| Nassau Co., N.Y. | 1977 | " | " |

There are another 30-50 carbon furnaces installed for use in connection with refining (decolorizing) of corn syrup and beet sugar.